Design and implementation of Hexa-triangular antenna for UWB wireless communication

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Abstract: *A modified hexagonal Sierpinski gasket-based fractal antenna is proposed for ultrawide-band (UWB) wireless applications. The designed antenna has miniaturized (36 48 mm^2) and multiband characteristics. Two design guidelines, the partial ground plane technique and the circular annular ring patch on the substrate, are applied to improve impedance matching and radiation pattern characteristics. According to the simulation results, the proposed modi ed antenna has a re ection coefficient S_{11} of less than {15 dB, a linear phase of the reflection coefficient, 80% radiation efficiency, 2{4.5 dBi antenna gain, and omnidirectional radiation pattern properties over the full UWB spectrum (3.1{10.6 GHz). Simulated results obtained for this antenna show the expected good radiation behavior within the full 7.5-GHz UWB bandwidth.*

Key words: *Ultrawide-band antenna, Sierpinski gasket, miniaturized, multiband*

I. Introduction

Rising bandwidth demands of wireless network subscribers due to the growth of high-quality multimedia services such as video conferencing and home video sharing push the wireless access network designs towards new alternative technologies. Ultrawide-band (UWB) signaling methodology has some unique characteristics for use in short-range wireless communication systems, which bring new opportunities for wireless coverage areas. UWB technology has some strong intrinsic features such as low self-interference, multipath immunity, minimal interference, and penetration through obstacles while preserving link integrity [1]. This technology has some state-of-the-art transmission characteristics such as ultrahigh bandwidths with noise-like power levels in a typical indoor environment (FCC part 15: {41.3 dBm/MHz) [2]. In the future, UWB systems are expected to operate in the entire UWB spectrum (3.1{10.6 GHz). Multiband orthogonal frequency division multiplexing (MB-OFDM) is an attractive modulation technique for multiuser UWB communication due to multipath energy efficiency, low interference between subcarriers, and high spectral efficiency [3]. Therefore, MB-OFDM based on UWB signaling methodology is projected to enhance a new perspective for high-de nition video communication in wireless personal area networks [4]. One of the challenging research objectives is to propose miniaturized, cost-effective antennas with power radiation uniformly in all transmission directions, ultrahigh bandwidth, and nondispersive behavior for UWB communication systems [5]. The antenna model is also critical since it has a major impact on the complexity and size of the receiver and transmitter designs for portable devices [6].

It was determined that planar monopoles offer compact, broadband, and omnidirectional characteristics for antenna designs [7]. Accordingly, several planar monopoles with different geometries have been proposed and experimentally characterized for wide-band applications [8{10]. Self-similarity and space- lling features are two well-known methodologies for achieving multiband and miniaturized characteristics for antenna designs [11].

Fractal geometries show key intrinsic properties as compared with traditional Euclidian ones, such as self-similarity, space- lling, and self-avoiding properties [12]. The space- lling characteristic could enhance the power transfer from the antenna design to the transmission medium (usually air) by utilizing smaller spaces. Consequently, miniaturization and operation on a desired frequency spectrum could be achieved.

There are several well-known fractal geometries for antenna applications in the literature that ensure small sizes and multiband characteristics, including the Hilbert fractal, Koch, Sierpinski gasket, Pythagorean tree, and Giusepe Peano designs [13{17]. In the current paper, the Sierpinski gasket (also known as the Sierpinski triangle) was chosen as a fractal geometry for antenna design since the design has a similarity to the well-known triangular concept. A fractal antenna is proposed in this paper in order to utilize the complete UWB spectrum (3.1{10.6 GHz) by introducing the hexagonal fractal structure formed by using six copies of the second-iteration triangular Sierpinski gasket. The mathematical generation of the hexagonal Sierpinski gasket is presented in the rst section by inheriting the center of masses of the subtracted triangles. The antenna re ection coefficient, gain, and radiation performance characteristics are shown in the second section. The proposed

antenna has good transmission characteristics with acceptable re ection coefficients, omnidirectional radiation patterns, and promising efficiency.

II. Antenna design

### 2.1. The ideal Sierpinski fractal concept

The Sierpinski gasket, or Sierpinski triangle, is a very popular fractal structure that was described by the Polish mathematician Waclaw Sierpinski in 1915 [18]. A self-similar current distribution that generates multiband behaviors for antenna designs is produced. The multiband characterization of the Sierpinski fractal antenna has been investigated and it was discovered that the perturbing of this fractal geometry can be used as a control technique for multiband behavior [19{22]. Furthermore, a Sierpinski gasket fractal-based antenna and closed-form mathematical calculations were proposed in [23]. A Sierpinski triangle is generated using a technique known as the iterative function system (IFS). The generation process of the proposed hexagonal Sierpinski-based monopole antenna is depicted in Figure 1.
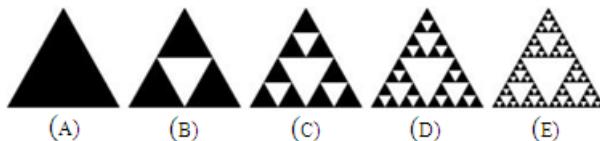
Figure 1. Sierpinski gasket generation process: (a) initiator, (b) 1st iteration, (c) 2nd iteration, (d) 3rd iteration, (d) 4th iteration.

The initiator (Figure 1a) is an inverted equilateral triangle; the equilateral nature allows for scaling symmetry and would also result in easy segment bisection. An equilateral triangle that is half the size (both width and height) of the main triangle is subtracted from the initiator to form the rst iteration of the Sierpinski gasket geometry, as depicted in Figure 1b. The subtraction is arranged in such a way that three equal-sized, equilateral triangles are generated. The edge of each newly generated triangle touches the other two triangles at a corner.

Figure 1b illustrates that the rst iteration generates a triangular hole in the middle of the main triangle shape. This is a result of the scaled-down triangles only taking 3 parts of the 4 part geometry, resulting in one remaining part un lled (a triangular hole). For the later iterations, the same subtraction procedure continues for the remaining triangles, as seen in Figures 1c, 1d, and 1e. When closely analyzed, it can be noticed that the Sierpinski set is a variant form of the repetitive structures that are said to be self-similar. The geometric construction of the Sierpinski fractal and the centric points of the subtracted triangles are depicted in Figure 2.
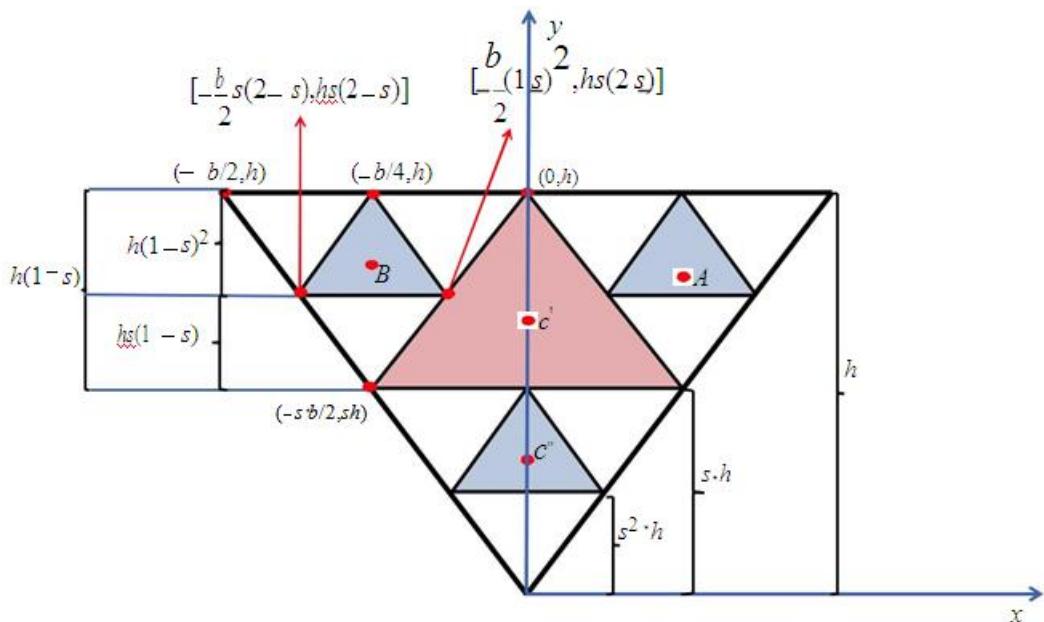
Figure 2. Mathematical representation for the generation of the 2nd iteration Sierpinski gasket.

The center of the main triangle shape, the initiator, is de ned as $c = (0; h=3)$. Mathematical representations are characterized in a general manner so that the perturbations on Sierpinski fractal structures can also be analyzed. In the proposed triangle, the two side lengths of the upside-down triangle are assumed to be a and the

top side is *b*. Mathematical representations are obtained in the case that $b \neq a$. On the other hand, the scaling factor (*s*) is de ned as 0.5 for ideal structures where $b = a$ as the side length of an equilateral triangle.

For later iterations, the center of the subtracted triangles from the rst iteration (c') and the second iteration (c'') are *A* and *B*: The coordinates of these centric points are de ned as follows:

$$X = \frac{x_1 + x_2 + x_3}{3}; \tag{1}$$

$$Y = \frac{y_1 + y_2 + y_3}{3} \tag{2}$$

From the above equations, we obtain:

$$c' = \left[0; sh + \frac{1}{3}h(1 - s) \right]; \text{ for } s = \frac{1}{2} : c' = \left[0; \frac{2h}{3} \right]; \tag{3}$$

$$c'' = \left[0; s^2 h + \frac{1}{3} sh(1 - s) \right]; \text{ for } s = \frac{1}{2} : c'' = \left[0; \frac{h}{3} \right]; \tag{4}$$

$$A = \left[\frac{b}{4}; \frac{h + 2sh(2 - s)}{3} \right]; \text{ for } s = \frac{1}{2} : A = \left[\frac{b}{4}; \frac{5h}{6} \right]; \tag{5}$$

$$B = \left[\frac{b}{4}; \frac{h + 2sh(2 - s)}{3} \right]; \text{ for } s = \frac{1}{2} : B = \left[\frac{b}{4}; \frac{5h}{6} \right] : \tag{6}$$

Dimensioning is a quite important terminology for fractal-based antennas in terms of size de nition. It can be described in several ways, but the simplest and best known one is the self-similarity dimension [24]. The self-similarity dimension for the Sierpinski gasket is shown below.

$$D = \frac{\log n}{\log \frac{1}{s}} \tag{7}$$

The number of copies of the initiator is speci ed with the parameter *n* and the geometry scaled-down fraction (*s*) is defined as 0.5 for the ideal Sierpinski gasket.
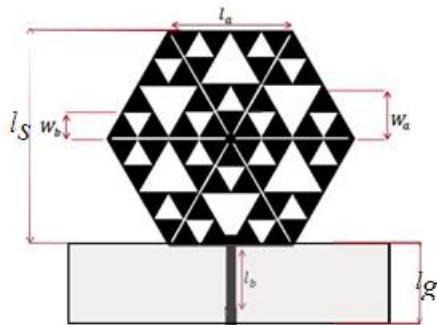
2.2. A modi ed hexagonal Sierpinski fractal antenna

The proposed modi ed hexagonal Sierpinski gasket antenna preserves most of the generation stages of the original Sierpinski fractal concept. Figure 3 shows the generation stages and the ultimate modi ed Sierpinski gasket. The generation process is exactly the same as the ideal Sierpinski gasket, with an equilateral triangle and a scaling factor ($s = 0:5$) up to the second iteration. This can be seen in Figures 3a, 3b, and 3c. The nal geometry is truncated after combining the six copies of the second iteration in a way that resembles a hexagonal structure, as shown in Figure 3d.

(A) (B) (C) (D)
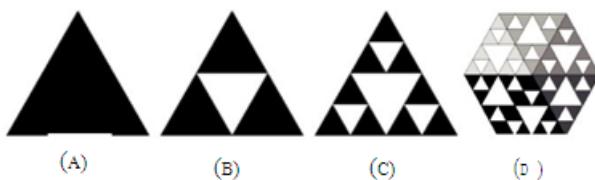
Figure 3. Proposed modi ed Sierpinski gasket antenna: (a) initiator, (b) 1st iteration, (c) 2nd iteration, (d) hexagonal Sierpinski gasket.

The hexagonal Sierpinski gasket fractal-based monopole antenna con guration is shown in Figure 4. The antenna was constructed on a Roger RO4232 substrate with a thickness of 1.45 mm, a relative dielectric constant ε_r of 3.2 and 0.0018 dielectric loss tangent, and a size of 36 48 mm (width height).

Figure 4. Dimensioning of the hexagonal Sierpinski fractal-based antenna structure.

The dimensions of the con guration are as follows: l_s = 24.4 mm, l_a = 14.2 mm, w_a = 7 mm, w_b = 3.5 mm, and l_b = 10.2 mm. A microstrip line with a feeding section is formed for the feeding section of the proposed antenna [25]. A modi ed ground plane is applied on the dielectric substrate with a 50- Ω microstrip feed line in order to achieve ultrahigh bandwidth with omnidirectional radiation characteristics.

III. Results and discussion

The proposed modi ed hexagonal Sierpinski fractal was generated with commercially available Ansoft HFSS software and simulated using the nite element method. An absorbing boundary condition environment was used to simulate in an open-domain transmission medium. The adaptive meshing technique was applied for the proposed simulation model (HFSS). The adaptation frequency was 6.9 GHz since it is a close value to the center of the full UWB spectrum (3.1{10.6 GHz). It was also observed that additional discrete frequency points improved eld performances for higher frequencies (above 9 GHz). Consequently, a further frequency sweep was applied at 10.3 GHz to achieve improved simulation results. As a rst research challenge, the proposed microstrip monopole antenna performance was studied with various ground plane lengths (l_g) . The simulated return loss (S_{11}) curves with diff erent values of l_g for the hexagonal Sierpinski antenna over the 3.1{10.6 GHz UWB range are shown in Figure 5.
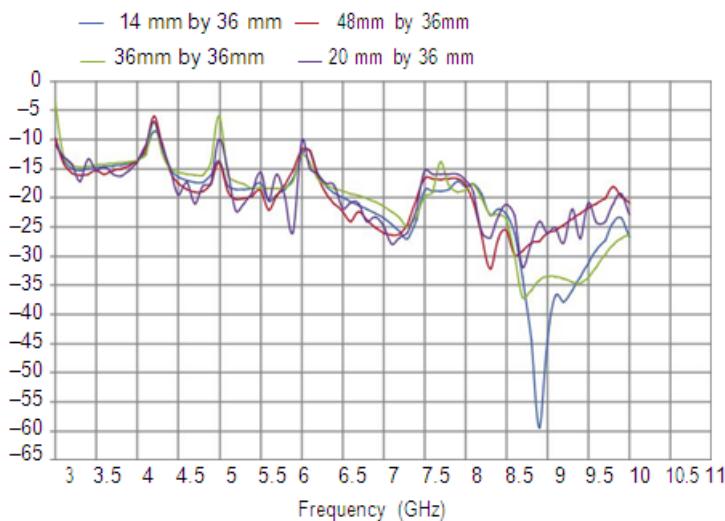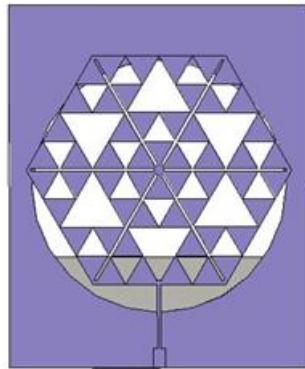

Figure 5. Simulated re ection coefficients of the proposed hexagonal Sierpinski antenna with different values of l_g .

The impedance bandwidth could be further enhanced by applying diff erent sizes of ground plane lengths, as shown in Figure 5. Values that were smaller than 14 mm had a minimal eff ect on impedance bandwidth. Therefore, the optimized value of l_g was chosen as 14 mm.
For further antenna matching improvements the circular annular patch technique was applied to the substrate [26].

The modifed hexagonal Sierpinski fractal-based monopole antenna picture with a circular ring patch is illustrated in Figure 6. The ring laceration on the substrate performs as an air dielectric that enhances the

reduction of surface wave excitation. With this technique, the electric eld could be increased without changing the physical size of the antenna. Accordingly, the input resistance of the antenna is improved for the proposed frequency range while keeping it compact.

The simulated return loss (S$_{11}$) curves with various circular ring patches for the proposed antenna over the UWB spectrum (3.1{10.6 GHz) are shown in Figure 7.


Figure 6. A picture of the proposed hexagonal Sierpinski fractal-based monopole antenna with a circular ring patch.
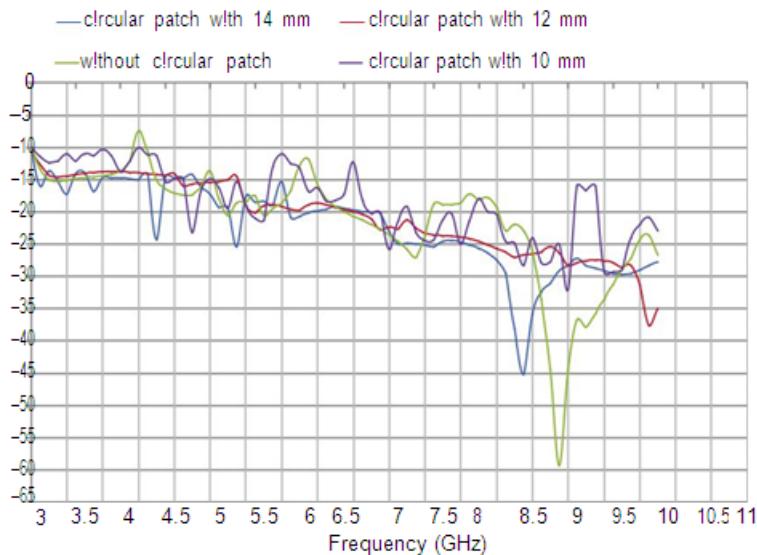
Figure 7. Simulated re ection coefficient versus frequency with diff erent values of circular patch.

After simulating for diff erent sizes of circular patches, it was observed that impedance bandwidth and radiation characteristics were improved. It was also realized that for all simulated sizes of the annular rings, S_{11} results were below {10 dB for the full UWB bandwidth. The optimized value for the circular patch was chosen as 14 mm.

It is well known that S$_{11}$ below {10 dB is satisfactory for UWB transmission. The proposed antenna showed eff ective matching properties with S_{11} below {15 dB. The rest of the simulation analysis was carried out by considering the optimized l_g and circular patch on the proposed hexagonal Sierpinski antenna. Figure 8 illustrates the simulated results of the voltage standing wave ratio (VSWR) for the proposed antenna. It can be observed that simulated VSWR readings are less than 1.5, implying an expected performance when considering return loss results.
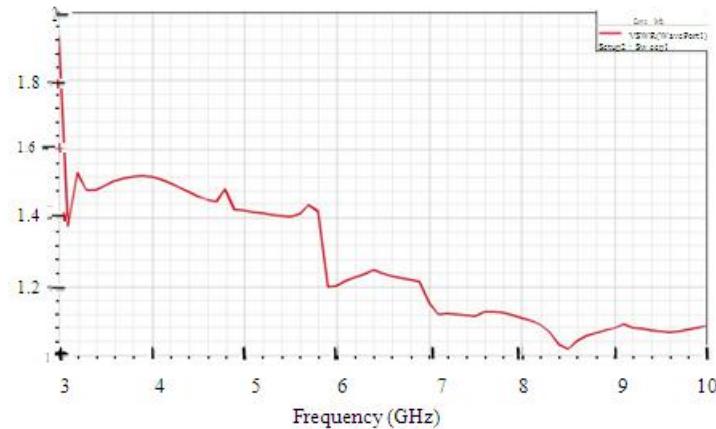
Figure 8. VSWR simulation results.

The plots in Figures 7 and 8 indicate that the antenna is matched and the input current is transmitted by the antenna. In UWB systems, it is quite crucial to achieve a linear phase response of the radiated eld and a stable group delay response over the full UWB spectrum. These characteristics enhance minimal distortion for the radiated pulse. As illustrated in Figure 9, the phase plot of the proposed antenna shows almost linear characteristics for the full UWB spectrum. Accordingly, the antenna group delay shows a persistent behavior over the 3.1{10.6 GHz range, as shown in Figure 10, which indicates a nondistorted time domain response of the proposed antenna design.
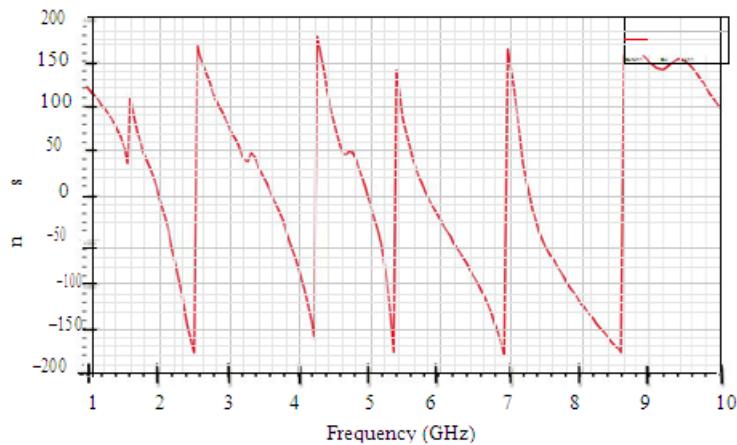

Figure 9. The phase of the re ection coefficient versus frequency for the proposed antenna.

Figure 11 illustrates the simulated two- and three-dimensional radiation patterns of the proposed antenna at various frequencies through the UWB bandwidth (3.1{10.6 GHz). The behavior of the E-plane and the H-plane of the proposed antenna is indicated by the purple and red lines, respectively, at various frequencies.

It can be observed from Figures 11a{11n that all of the patterns are omnidirectional and provide spherical coverage with stable radiation patterns over the full UWB range (3.1{10.6 GHz). At 10 GHz and above, however, the antenna is expected to experience losses in gain and range; this can be ascribed to limitations in the substrate and higher mode excitation by the structure. Most of the patterns have an `8'-shaped pattern corresponding to a 3D pattern with a toroidal shape. The simulated patterns are expected due to the characteristics of the printed monopole. The antenna gain versus frequency is depicted in Figure 12, showing a satisfactory antenna gain in the UWB range. There is a slight increase observed at higher frequencies as a result of the directional patterns.
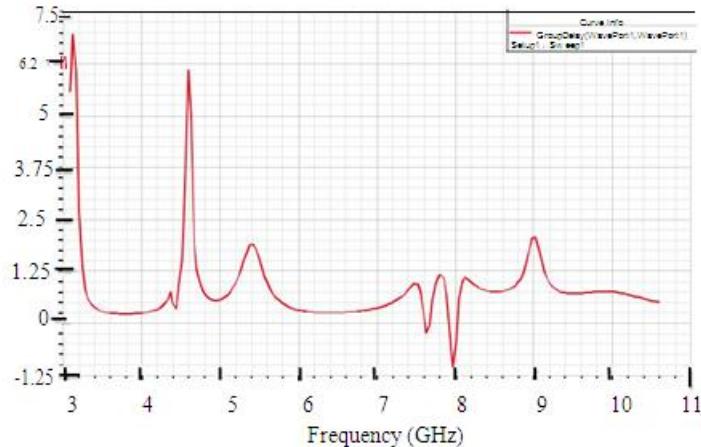
Figure 10. Group delay for the modi ed hexagonal Sierpinski gasket.
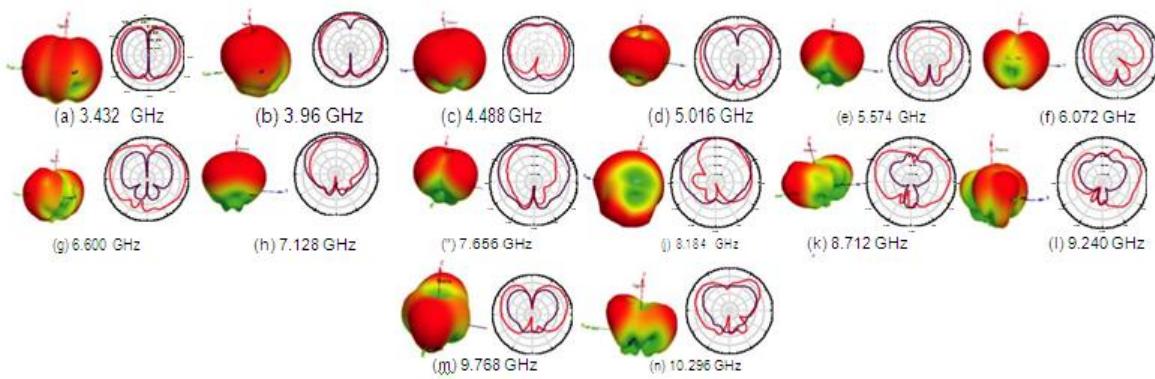
Figure 11. Radiation patterns of the proposed antenna over the UWB bandwidth (3.1{10.6 GHz).
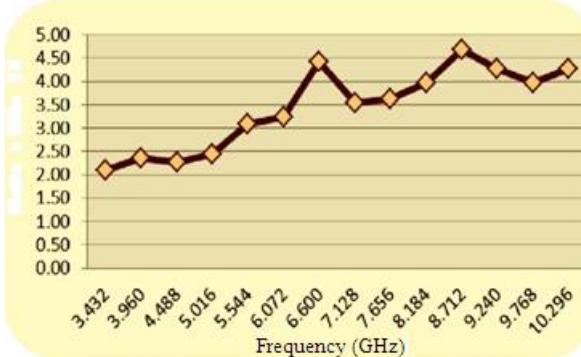
Figure 12. Antenna gain over UWB bandwidth.

IV. Conclusions

A miniaturized (36 48 mm^2) antenna design is proposed by utilizing the space- lling and self-similarity prop-erties of fractal geometries. The antenna is based on hexagonal Sierpinski fractal geometry and has multiband, broadband, and good electrical characteristics. The proposed antenna is characterized for the complete UWB spectrum (3.1{10.6 GHz). Better antenna characteristics are achieved by applying the partial ground plane technique and inserting a circular patch to the substrate. Based on the results, we can conclude that there is a matched impedance bandwidth in the full-band UWB range with desired re ection coefficient characteristics (better than {15 dB). In line with these characteristics, the proposed antenna has 80% radiation efficiency over the full UWB bandwidth. The radiation patterns show omnidirectional transmission performances. The pro-posed miniaturized hexagonal Sierpinski-based fractal antenna demonstrates efficient performance results that can be used for UWB communication.

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