Fractal Antenna for Multiband Applications

Abhishek Kulshrestha
Department of Electronics and Communication engineering,
RKDF Institute of Science &Technology, Bhopal, M.P., India

Bhagwat Khakde
Department of Electronics and Communication engineering,
RKDF Institute of Science &Technology, Bhopal, M.P., India

Abstract- In this paper, multiband fractal antenna are proposed. The proposed multiband antenna design is based on a methodology that utilizes the self transformation principle of fractal-like rectangular profiles to generate multiband operation. The proposed monopole-type antennas are built on a partial ground plane and fed through a microstrip feed line. The analytical design procedures are straightforward and can be applied to any practical antenna structure to operate at multiple preselected bands. The developed methodology has been used to design antennas operating at three and four preselected practical bands. Numerical simulations are utilized to verify the simple design procedures of the proposed multiband antenna structures. The triple-band and the quad-band structures have been realized on FR4 substrate to prove the concept. Simulation and experimental results are in good agreement and demonstrate the performance of the design methodology and the proposed antenna structures.

Keywords – fractal antenna, Multi-Band Antenna, monopole-type antennas, slot antenna, CST simulator.

I. INTRODUCTION

A continous growth in wireless communication system demands more complex and sophisticated systems along with more operating bands. In mobile communication systems many different frequency bands are needed such as global system for mobile communication (GSM800/900), digital communication system (DCS), personal communication system (PCS), universal mobile telecommunication system (UMTS) and the industrial scientific and medical (ISM)band [1]. Multiband antennas are also very attractive candidates for application in communication devices for global positioning system (GPS) and Bluetooth and Wireless Local Area Network-WLAN 802.11b/g system bands. To satisfy these demands, antenna designers try to achieve small, light weight, and low profile multiband antennas [2]. Fractal antennas have received much attention from antenna designers to make multiband antennas because they are light-weight, low profile, conformal and easy to combine with other circuit structures. Several fractal configurations have been suggested for GSM/DCS/WLAN,900/1800/2450MHz bands in recent publications as the fractal shapes consists of self-similarity and can be applied to design multiband antennas. It has been demonstrated that fractal shapes [3, 4] are suitable solutions for both miniaturization [5, 6] and multi-band operation [7, 8]. Fractal geometries are fragmented geometries that can be subdivided in parts, each of which is a reduced copy of the whole. Fractals are generally self similar and independent of scale. Self-similarity is probably one of the most important characteristics of fractal profiles. The Sierpinski gasket monopole antenna has been designed by decomposition method [9]. A modified Sierpinski fractal broadband antenna for multiband application was proposed in [10]. A triple band planner antenna working in the GSM and UMTS frequency bands was presented in [13]. In [14], a simple microstrip-line-fed monopole antenna for triple band wireless applications was designed.

. In this paper, fractal-like geometrical structures with self transformation property have been investigated for multiband wireless communications antenna applications. A simple design methodology based on the self transformation of fractal-like multi-rectangular-slot geometries has been developed and elucidated in the next section. This systematic approach can be applied to design multiband antennas operating at predetermined multiple bands on suitable substrates with partial ground plane ensuing wide operating band-widths. Based on that, novel triple-band, quad-band, and pent-band fractal-like antennas have been designed and presented in this paper. The effect of the geometrical iterations and the self-transformation factors on locating the operating-bands is investigated as well. The introduced rectangular-slot-based fractal-like microstrip antenna geometries are not only simpler than the classical complex triangular fractal geometries but they, also, have more controllable and flexible superior multiband operation. Numerical simulations using full wave electromagnetic (EM) MoM-based CST simulator are used to verify the systematic design approach. Two triple-band and quad-band antenna structures have been realized on FR4 dielectric substrate material with 4.7 relative permittivity and 0.78mm thickness. Simulation and experimental results express the good matching and radiation performance of the designed multiband antennas without an extended ground plane.

II. Proposed Algorithm

The proposed fractal-like antenna is shown in Figure 1. This fractal-like antenna has repeated (iterated) simple rectangular slots instead of the standard multiple isosceles triangles. Such fractal-like antennas can operate at multiband depending on their geometries. The proposed multiband antenna is constructed by applying a geometric transformation on the triangular base-region of the bowtie monopole antenna of Figure 1(a). Subtracting the inverted gasket triangle to the rectangular shape, the fractal-like monopole in Figure 1(b) is obtained. Repeating the procedure more than one time, results in the fractal like monopoles shown in Figures 1(c) and 1(d). The first band of such structures corresponds to the fundamental frequency of the bowtie monopole [11] and can be approximated by,

$$f_0 \approx \frac{c}{2L_e\sqrt{\varepsilon_r}} \qquad (1)$$

where, *c* is the speed of light in vacuum, *Le* is the effective length which is the sum of strip feed line and length of the triangle, i.e.,

$$Le = L + p \qquad (2)$$

where, *L* and *p* are the lengths of the triangle and the strip line indicated in Figure 2.

The second and higher bands are log-periodically spaced by a ratio which is determined by the iterative construction procedure and the self transformation factor or space factor. It can be calculated as [11];

$$\psi = \frac{h_e}{h_e + 1} \qquad (3)$$

where, ψ and *h* are the self transformation factor and height of the gasket, respectively. The second band is analogous to that of classical Sierpinski fractal shape [11] and can be calculated approximately using an empirical relation developed from [9] and given as;

$$f_1 = 0.52\frac{c}{L_e} \qquad (4)$$

Where, *c* is the speed of light in vacuum, *Le* is the effective length of the largest gasket. Higher bands are, then, calculated simply from the self transformation (space) factor of the structure. The number of the antenna's operating-bands is determined by the number of geometric iterations and it is equal to the number of iterations. The number of the generated rectangular slots in the geometry is one less the number of the operating bands of the antenna. The proposed multiband fractal-like monopoles possess good matching performance with compact partial-ground plane unlike classical fractal structures presented in [11] and [12].

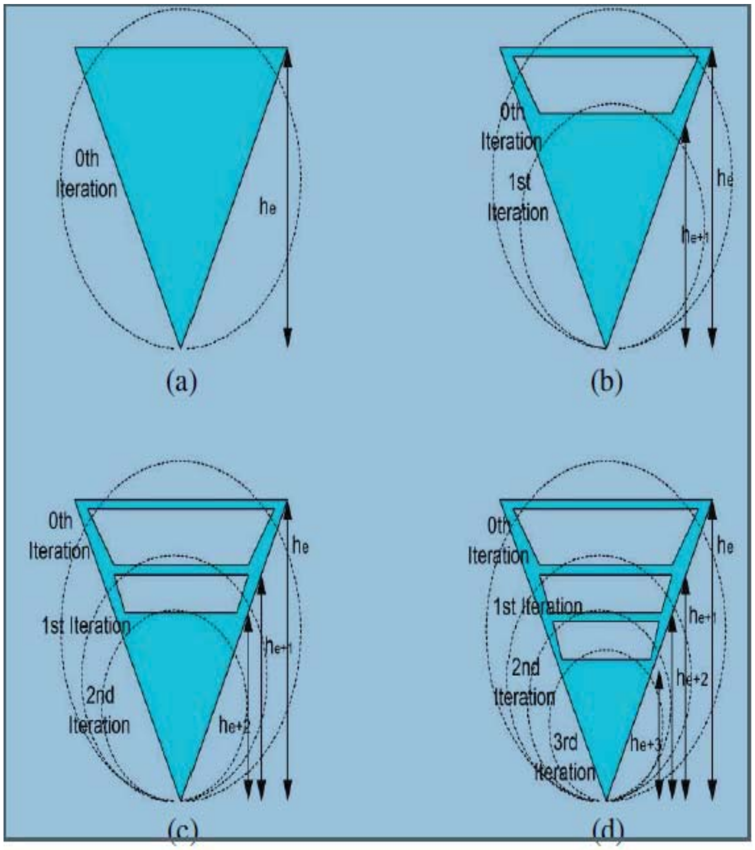


Figure1. Generation of multiband fractal geometries.

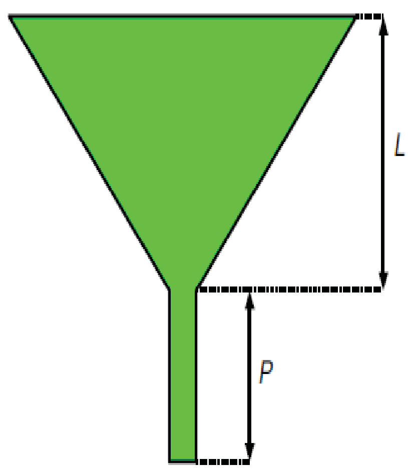


Figure 2. Triangular shape indicating lengths of the triangle and stripline.

III. ANTENNA DESIGN AND RESULT

A. Triple-band Fractal-like Antennas

The triple-band fractal-like antenna is designed by performing three iterations to operate at three preselected frequencies. Simple antennas designs on FR4 dielectric substrate with thickness, q = 0.78mm and relative Permittivity ε_r =4.7 are used to demonstrate the design concept. The fractal-like antenna with a total dimension of 62× 89.6 × 0.78 mm^3, is fed by a microstrip line placed at the centre axes of the dielectric substrate as shown in Figure 3.

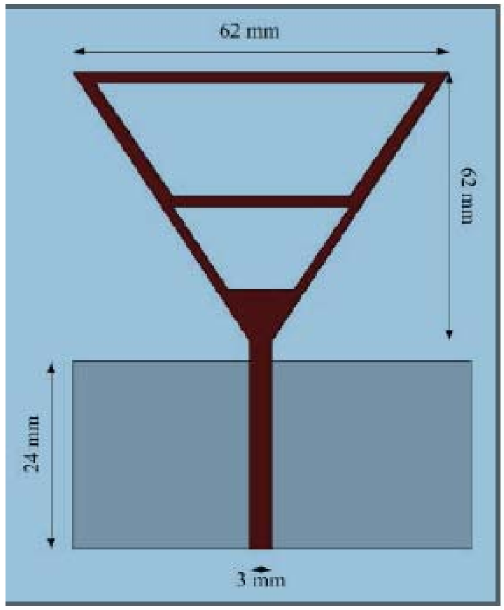
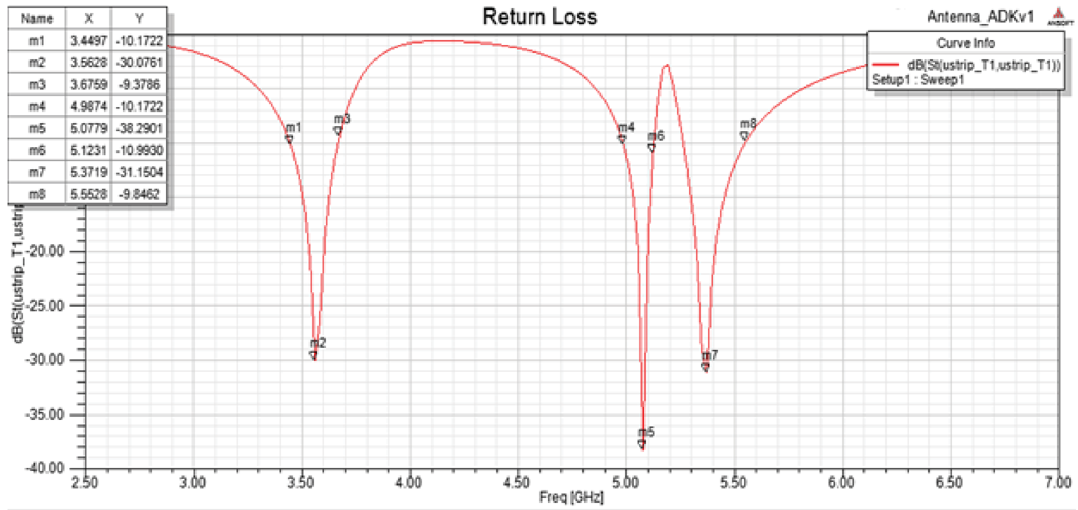


Figure 3. Triple band fractal-like antenna with ψ = 1.25.

The partial ground plane which is on the other side is only 62×24 mm^2. The Triple band fractal-like antenna design with various self transformation factor of 2, 1.5, and 1.25. In case of self transformation factor of 1.25 has better performance than other two self transformation factors.

The 50Ω return loss of the triple band fractal-like antenna in Figure 4 shows that the second and third bands are spaced by a scale factor of 1.25. The first resonance occurs at f_1 = 3.55GHz, the second resonance occurs at f_2 = 5.1 GHz, and the third resonance occurs at f_3 = 5.4 GHz.

the return loss plot S_{11} plot shows that the first resonance frequency is at f_1 = 3.55 GHz, the second resonance occurs at f_2 = 5.1 GHz, and the third resonance occurs at f_3 = 5.4GHz. The bands cover the practical operating frequencies of WiMAX/WLAN applicationos.



. Figure 4. Computed return loss (S_{11}) of quad band fractal-like antenna with ψ = 1:25.

B. Quad-band Fractal-like Antenna

The quad band fractal-like antenna presented here consists of a partial ground plane and microstrip feed line whose three rectangular-slot geometry is shown in Figure 5. The dimension of the proposed quad-band fractal-like antenna is same as the previous examples.

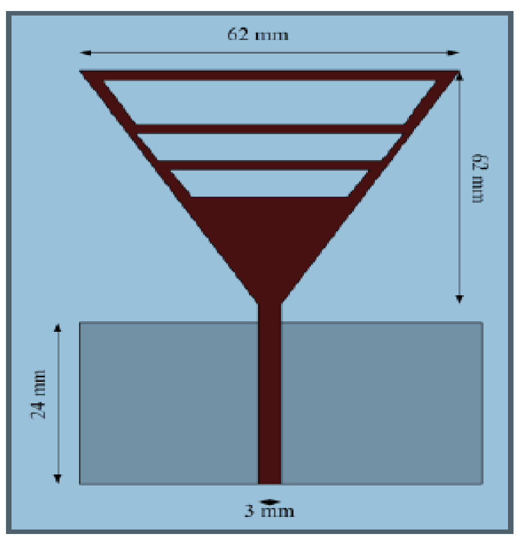


Figure 5. Quad band fractal-like antenna with ψ = 1.25.

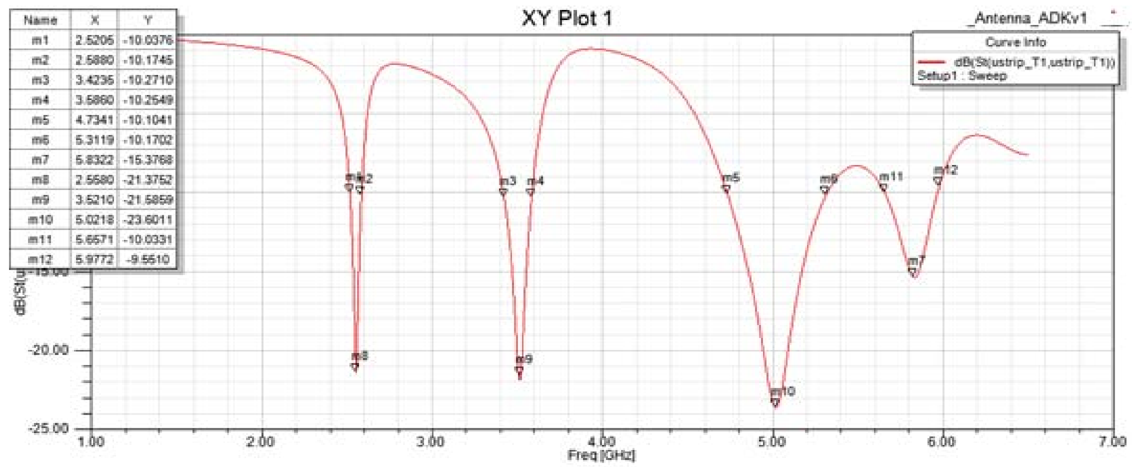


Figure 6. Computed *S*11 of quad band fractal-like antenna with ψ = 1.25.

Return loss plot shows that the first resonance frequency occurs at f_1 = 2.5GHz, second resonance occurs at f_2 = 3.5 GHz, the third resonance occurs at f_3 = 5GHz and the fourth resonance occurs at f_4 = 5.8GHz. These bands cover the operating frequencies of WiMAX/WLAN applications allocated bands.

C. Radiation characteristics

To examine the radiation of the multiband fractal antenna structures, the computed radiation patterns of the quad band fractal antenna of Figure 9 are depicted in Figure 13. The radiation patterns of the total radiated field at two orthogonal planes; $\varphi = 0^0$ and $\varphi = 90^0$, at the four resonance frequencies; 2.5 GHz, 3.5 GHz, 5 GHz and 5.8 GHz are shown in the figure. The antenna confers a dipole like patterns with an omnidirectional behaviour at $\varphi = 0^0$ plane.

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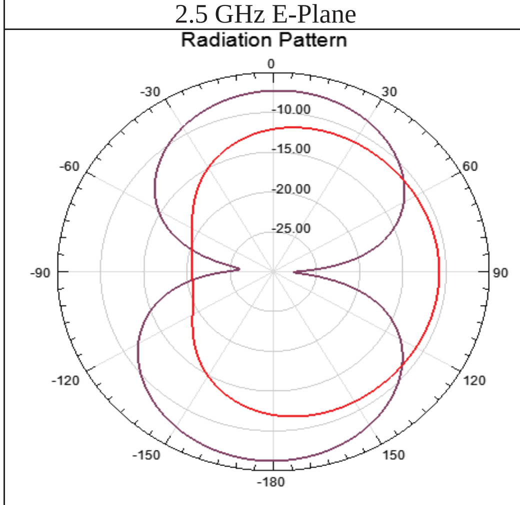
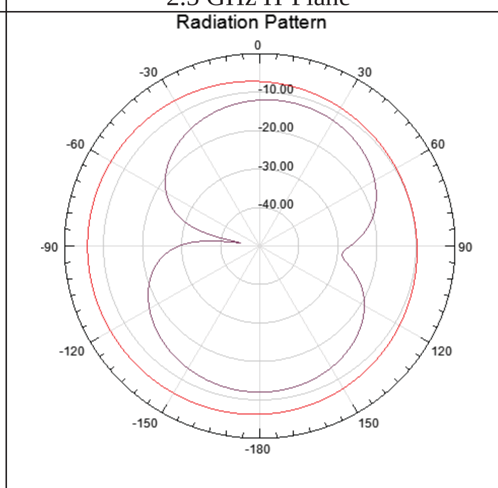
<tr><td>2.5 GHz E-Plane</td><td>2.5 GHz H-Plane</td></tr>
<tr><td>
</td><td>
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<tr><td>3.5GHz E-Plane</td><td>3.5 GHz H-Plane</td></tr>
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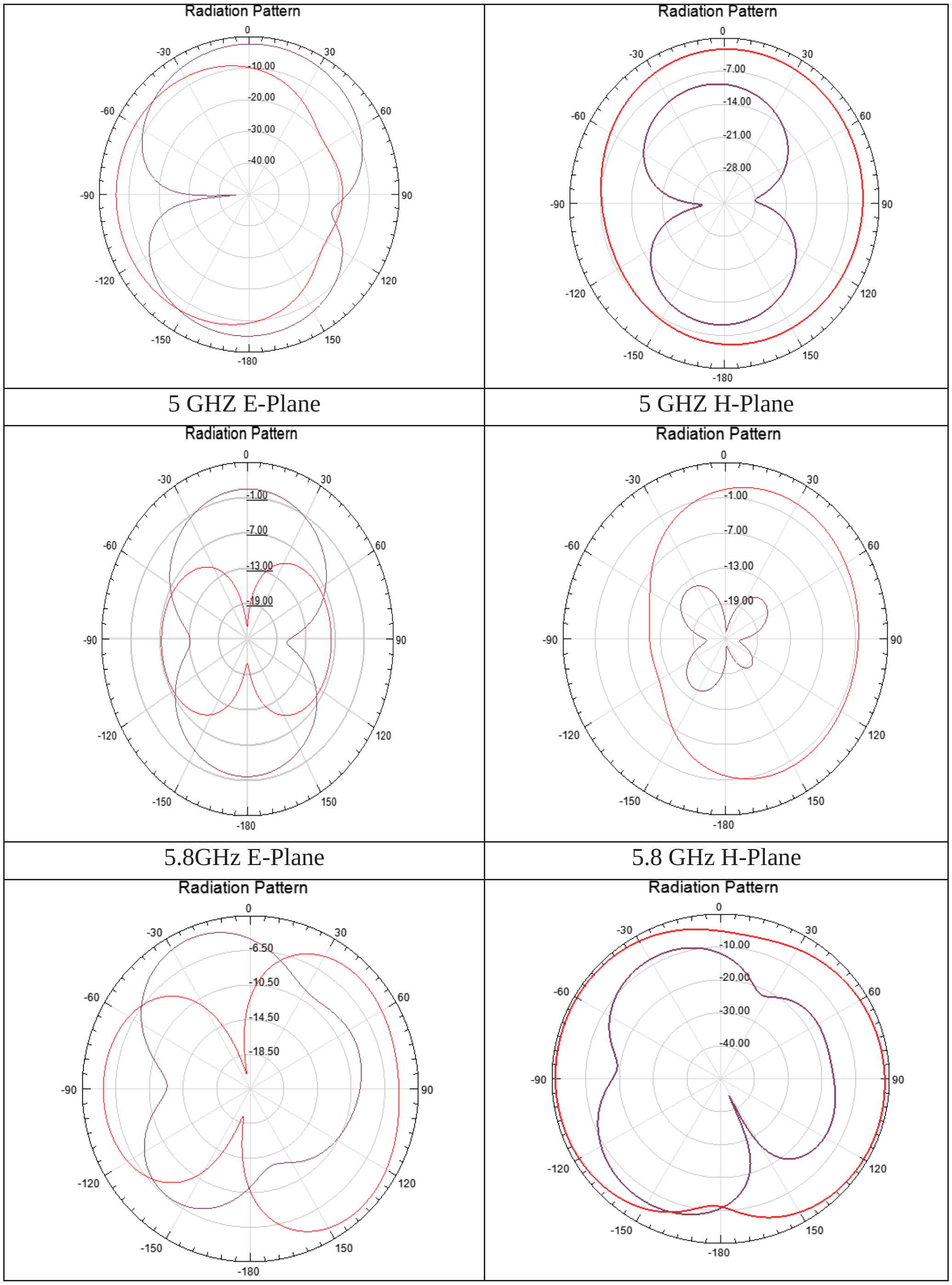

Figure 7. radiation patterns of the proposed quad-band fractal-like antenna at (a) 2.5GHz, (b) 3.5 GHz, (c) 5GHz, (d)5.8 GHz.

The antenna radiation characteristics at the first band are very similar to that of the basic bow-tie monopole at its resonance frequency. The gain of the antenna at the four bands is between 4 dB at the lower band and 8 dB at the higher band as expected for microstrip monopole structures. The computed radiation efficiencies of the quad-band antenna are in the range of 90-95%

D. Radiation efficiency, Peak Gain & Peak Directivity

PARAMETER	5.8GHZ	5GHZ	3.5GHZ	2.5GHZ
Radiation efficiency	95.84%	98.47%	97.26%	96.16%
Peak Gain	3.15dB	7.627dB	2.58dB	4.5dB
Peak Directivity	3.50	3.44	3.18	3.61

Table 1 : Result of Quadband fractal Antenna

Table 1. shows the Radiation efficiency, Peak Gain & Peak Directivity performance of our proposed fractal Antenna for multiband applications has a better performance than others.

IV.CONCLUSION

Fractal-like geometrical structures with self transformation property have been investigated for multiband communications antenna applications. A simple design methodology based on the self transformation property of fractal-like geometries has been developed. This systematic approach can be applied to design multiband antennas operating at predetermined multiple practical bands on suitable substrates. Accordingly, new multiband fractal-like antennas have been designed and proposed in this paper. The proposed antennas are with simple multi-rectangular slot geometry and built on a partial ground plane fed through a microstrip feed line. The control of the locations of the antenna multiple operating-bands by the space factor has been demonstrated as well. The designed antennas are simulated using a full wave electromagnetic (EM) simulator and then two triple and quad-band antenna structures were realized on FR4 dielectric substrate material with relative permittivity of 4.7 and thickness of 0.78 mm. Simulations and experimental results are in good agreement and reveal the matching and the radiation performance of the proposed Compact ground-plane fractal-like multiband antennas.

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