A Novel Planar Fractal Antenna with CPW-Feed for Multiband Applications

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Abstract. *In this paper, a multiband antenna using a novel fractal design is presented. The antenna structure is formed by inscribing a hexagonal slot within a circle. This base structure is then scaled and arranged within the hexagon along its sides without touching the outer structure. The proposed CPW fed, low profile antenna offers good performance in the 1.65 – 2.59 GHz, 4.16 – 4.52 GHz and 5.54 – 6.42 GHz bands and is suitable for GSM 1800/1900, Bluetooth, IMT advanced systems and upper WLAN applications. The antenna has been fabricated on a substrate of height 1.6 mm and* $\varepsilon_r = 4.4$ *and simulation and experimental results are found to be in good agreement.*

Keywords

Fractal, multiband, CPW, hexagon, iteration, WLAN, GSM.

1. Introduction

Rapid growth in the wireless communication industry poses a requirement for complex systems capable of operating in multiple bands. Various applications such as GSM 800/900, PCS and GSM 1800/1900 use the lower end of the UHF band while WLAN and UWB operate in the upper UHF band. In addition to multiband operation, it is necessary that the antenna is small, light weight, low profile and can be easily integrated with other microwave components. Planar antennas with CPW (coplanar waveguide) feed have received much attention [1]-[3] due to their wideband characteristic and ease of integration with MMICs. Fractal antennas are commonly used due to their inherent properties like small size, and multiband capability [4]-[6]. Recently, several fractal trigonometric shapes have been investigated and many designs have been used to develop ultra wideband antennas [7]-[9]. But in such structures, the group delay degrades as fractal iterations increase.

The self similarity property of the fractal antenna leads to multiband operation because it operates in a similar manner at several wavelengths. A popular antenna using the self similarity property of fractals is the Sierpinski gasket monopole [10]. Several other monopole structures have been developed using the fractal concept to achieve multiband behavior such as a Penta-Gasket-Koch fractal [11], Minkowski fractal [12], triangular monopole with rectangular slots [13], multiple monopole rings [14] and Sierpinski sieve [15].

In this paper, a novel planar fractal antenna with CPW feed is introduced for multiband purposes. The antenna operates in global system for mobile (GSM) and Bluetooth (1.65 – 2.59 GHz), IMT advanced system or fourth generation (4G) mobile communication system (4.16 – 4.52 GHz) and upper wireless local area network (WLAN 5.54 – 6.42 GHz) bands. The basic structure is a circular monopole antenna which exhibits wideband characteristics. Multiband operation is achieved by inserting a fractal pattern in this structure. The prime novelty in the proposed structure is that the inner structure formed after the first iteration is not connected to the feed element. This suggests a coupling of energy from the outer structure to create an additional resonance. The simulated results show that the proposed antenna has good efficiency in all the intended bands of operation. Section 2 presents the details of the antenna structure and fractal design. Section 3 discusses the obtained results and compares simulated and experimental data. Conclusion is presented in Section 4.

2. Antenna Geometry

The geometrical configuration of the proposed antenna is shown in Fig. 1. The base fractal is obtained by cutting out a hexagon from a circular patch. This is scaled and then arranged in a hexagonal pattern to obtain the structure of iteration 1. Now within each hexagon, the pattern is repeated to obtain the structure of iteration 2.

Fig. 1. Configuration of the proposed antenna.

Fig. 2 shows a plot of S_{11} for different iterations. The basic circular monopole gives a very wideband characteristic and inscribing a hexagon within the structure results in the base fractal with two application bands. The radius of the circle with inscribed hexagon is then scaled down and six such structures are arranged in a hexagonal manner to obtain the configuration of iteration 1. The first iteration results in an additional band close to WLAN frequency of 5.45 GHz and thus a total of three 2:1 VSWR bands. The results obtained with the second iteration did not vary significantly from that of first iteration and also due to fabrication difficulties, this configuration was not considered further.

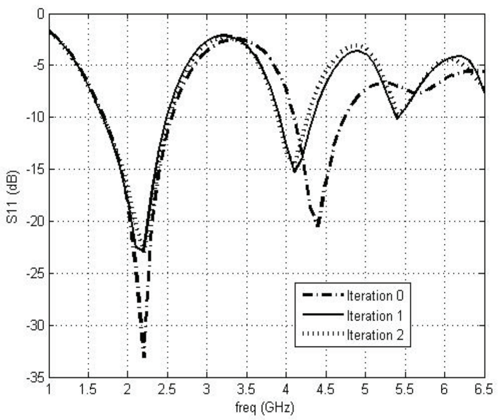


Fig. 2. Simulated S_{11} of proposed antenna structure for various iterations.

In this paper, the structure obtained after first iteration is investigated with dimensions as shown in Fig. 3.The antenna is fed by a 50-Ω CPW and is printed on a substrate of size 34 x 51 mm^2. The substrate used is of thickness h = 1.6 mm, relative dielectric constant $\varepsilon_r = 4.4$ and loss tangent tan $\delta = 0.02$. The width and length of the CPW feed line are 3 mm and 17 mm respectively.

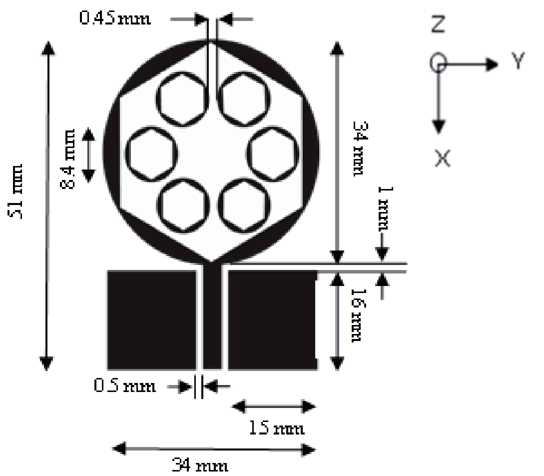


Fig. 3. Dimensions of fractal antenna.

The radius of the circular monopole is calculated [17] for a resonance frequency of 2.45 GHz. The hexagon inscribed within the circle has a side that is approximated as

$$l = \frac{\lambda}{4} = \frac{c}{4 f_r \sqrt{\varepsilon_r}}$$

where c is the free space velocity, f_r is the resonant frequency and ε_r is the relative permittivity of the substrate. The side of the hexagon controls the first resonant frequency and the diagonal which is twice the side length, controls the second resonant frequency.

The scaling factor for obtaining the structure of first iteration was optimized using Ansoft HFSS and the simulated S_{11} results with different scaling factors are shown in Fig. 4. It was found that for scaling factor 0.3 and greater, the structure exhibits wideband characteristics and for scaling factor 0.2 or lesser, the S_{11} is very similar to that obtained with iteration 1. However, for scaling factor 0.25, improved impedance matching was obtained at 5.45 GHz.

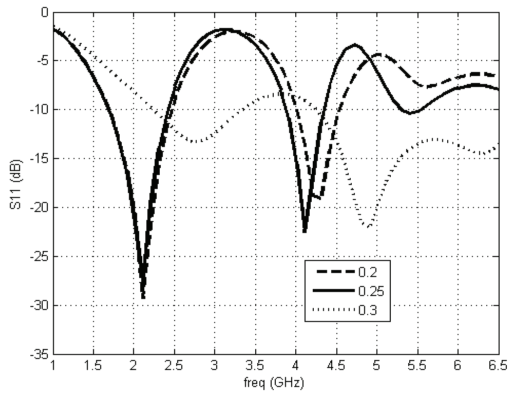


Fig. 4. Simulated S_{11} for different scaling factors.

The proposed antenna was designed and simulated, with the same scaling factor of 0.25, on different substrates and the results are shown in Fig. 5. On all the substrates the antenna exhibits triple band behavior in similar frequency ranges which ensures repeatability of the proposed design.

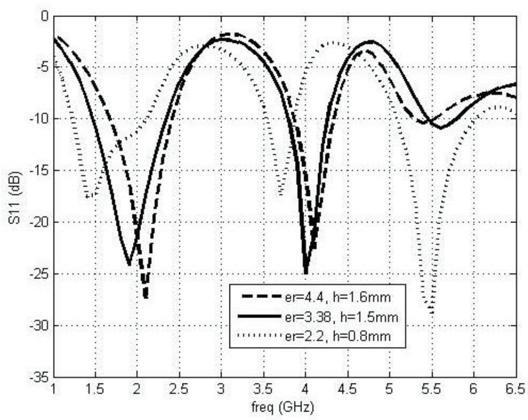


Fig. 5. Simulated S_{11} for proposed antenna design on different substrates.

3. Simulation and Experimental Results

In this section, full wave analysis of the proposed antenna in frequency domain is presented. The simulated S_{11} of the proposed antenna is compared with the experimental results and shown in Fig 6. The results show fairly good agreement up to 5.5 GHz. At higher frequencies, the measured and simulated results show some difference. This may be due to uncertainty in thickness and/or dielectric constant of substrate and soldering effects of the SMA connector, which have been neglected in the simulations. But the structure still exhibits triple band behavior as obtained with simulated results. The measured bandwidths are from 1.65 – 2.59 GHz, 4.16 – 4.52 GHz and 5.54 – 6.42 GHz for $S_{11} \leq$ -10dB which corresponds to VSWR <2.

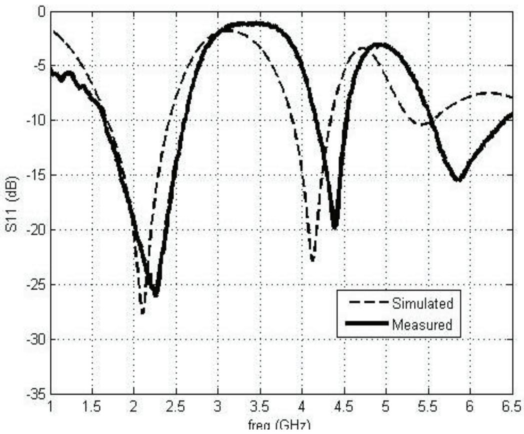
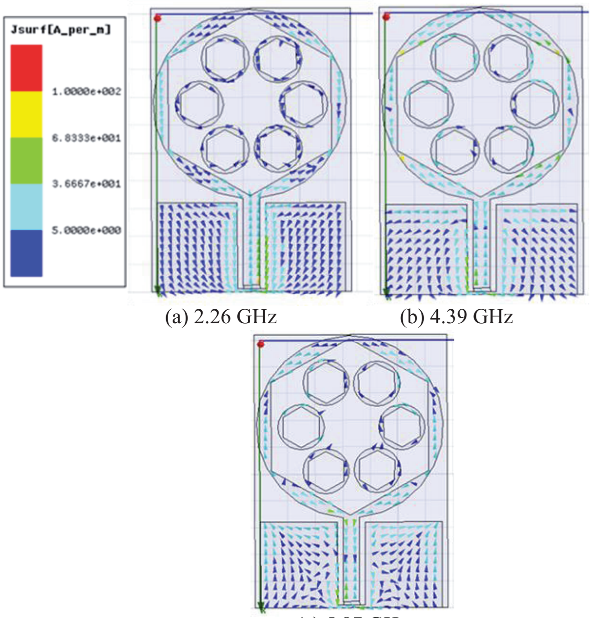


Fig. 6. Simulated and Measured S_{11} in dB.

The surface current distribution of the antenna at the resonance frequencies is shown in Fig. 7 (a)-(c).



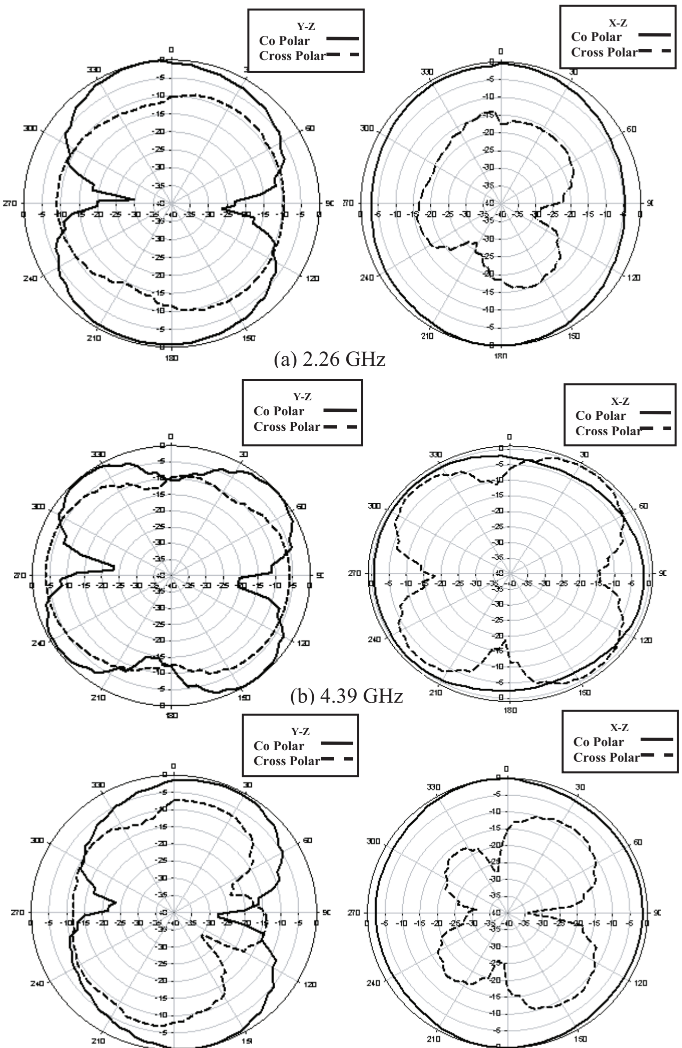
(a) 2.26 GHz (b) 4.39 GHz

(c) 5.87 GHz

Fig. 7. Simulated surface current distribution of proposed antenna at resonance frequencies.

It is seen that the first resonance is due to one full wave variation of current distribution along the sides of the hexagon, while at the second resonance, there is significant concentration on the corners of the hexagon. The variation of the current distribution along the feed line at the highest resonance frequency suggests the excitation of higher order modes.

Normalized radiation patterns of the antenna measured at the resonant frequencies 2.26 GHz, 4.39 GHz and 5.87 GHz are shown in Fig. 8 (a)-(c). The antenna has a figure-8 pattern in the y-z plane with half power beam width (HPBW) of 86°, 40° and 76° at the above three resonant frequencies respectively. In the x-z plane the pattern is non directional in all the frequency bands of interest like that of an ordinary dipole antenna. The antenna has linear polarization, good radiation pattern stability and the omni-directional radiation performance makes it suitable for application in wireless devices.



(a) 2.26 GHz

(b) 4.39 GHz

(c) 5.87 GHz

Fig. 8. Measured normalized radiation pattern of antenna at resonant frequencies.

The simulated results of gain of the designed antenna are shown in Fig. 9. It is found to be greater than 1.5 dBi with efficiency above 85 % in all the intended frequency bands.

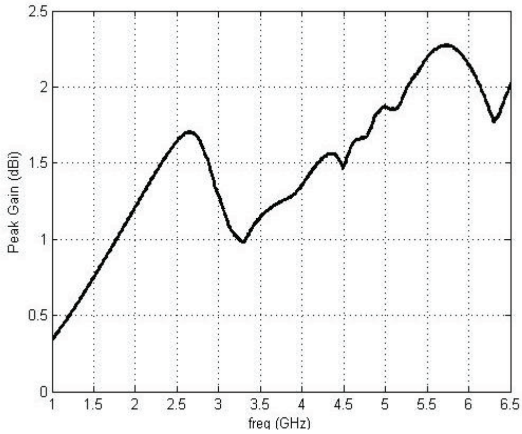


Fig. 9. Simulated gain of the proposed antenna.

A photograph of the fabricated antenna including feeding port is shown in Fig. 10. The characteristics of the antenna are compared with few reported antennas and shown in Tab. 1.

Fig. 10. Photograph of fabricated antenna.

Antenna	Number of operating bands	Antenna Size (mm^3)	Peak Gain (dBi)
Proposed antenna	3	34 x 51 x 1.6	1.5-2
[12]	3	48 x 50 x 0.8	1-3.5
[13]	5	62 x 89.6 x 0.78	1-4
[15]	3	80 x 40 x 1.6	4-7

Tab. 1. Comparison between recently reported antennas and the proposed antenna.

When comparing the antenna with some of the recently proposed multiband antennas, the antenna is found to be compact and design is simple. The peak gain is slightly lesser but this can be attributed to the small size. The results show that the antenna is a suitable candidate for wireless applications.

4. Conclusion

A new planar fractal antenna with two iterations has been introduced. The antenna exhibits good performance in three bands, 1.65 – 2.59 GHz, 4.16 – 4.52 GHz and 5.54 – 6.42 GHz. The antenna is compact, simple to fabricate, exhibits moderate gain and stable radiation patterns make it suitable for multiband wireless applications.

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