Design of Compact Dual-band Antenna for 4G LTE Wireless Devices

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ABSTRACT

In this paper, the planar dual-band monopole antenna is presented for Long Term Evolution (LTE) and Wireless Local Area Network (WLAN) applications. The design of the proposed antenna is based on Peano fractal curve and meander line structures. The antenna operates in 1.71 GHz to 2.01 GHz in the desired LTE frequency band and 5.0 GHz to 5.5GHz band (IEEE 802.11a band). The frequency band 1.71 - 2.01 GHz is already available as a study of the current plan according to UMTS and LTE systems (the band no.4). The antenna has been fixed on a substrate board Arlon with ε_r= 2.33 and thickness of 0.9 mm. Simulation results shows that the proposed antenna has promising radiation characteristics and a reasonable gain of 2.155 dBi at the lower band and 4.772 dBi at the upper band. The simulation and evaluation of antenna performance werecarried out using Microwave Studio Suite of Computer Simulation Technology CST.

Keywords: Peano fractal geometry; dual-band antenna; compact size antenna

INTRODUCTION

Dual-band and Multiband small planar antennas are becoming increasingly popular in personal wireless communication systems since these antennas offer advantages such as small size, light weight, robust construction, and ease of integration into mobile handsets, reasonable radiation efficiency and gain [1]. Small size (miniaturization) and multiband can be achieved through using different techniques like fractals [2].

Fractal geometries are characterized by two unique properties; space-filling and self-similarity [2,3]. The first property enables the compact antenna design, while the multiband antenna operation is attributed to the second property. In this respect, structures with various configurations that are based on fractal geometry become popular in the design of compact and multiband antennas [4-10]. Printed and patch antennas with structures in the form of Minkowski [4-5], Koch [6-7], Moore [8], Hilbert [9],Peano [10]and other fractal geometries are used to design compact size antennas with multiband operation.Furthermore, slot antennas with slot structures based on Koch [11], Peano [12-13], Cantor [14] fractal geometries have been successfully used in the design of multiband and dual-band antennas for a wide variety of wireless applications.

Peano fractal geometry and its variants have shown to be an attractive choice for microwave engineers and designers seeking for compact and miniaturized antenna and circuits to fulfill the requirements of compact size wireless communication systems [10, 12-16]. In antenna design, Peano fractal curve and its variants are among the first fractal geometries adopted to design compact and multiband antennas [10, 12-13]. In filter design, Peano fractal based structures are used to design compact single mode bandpass filters [14] and dual-mode bandpass filters [15-16]

On the other hand, the design of antennas that are based on hybrid structures composed of more than one fractal geometry has been reported in the literature [18-20]. The combined fractal

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antenna structures have been adopted for two reasons. The first is to gain more miniaturization that a single fractal curve cannot achieve. This will lead to reduced lower resonant frequency or reduced antenna size if the lower resonant frequency has to be maintained unchanged. The second reason is to realize different ratio of the upper to lower resonant frequencies suitable for specific communication applications.

In this paper, the procedure for designing a compact planar monopole micro strip antenna based on Peano-curve type fractal geometry and meander line is presented and the results obtained from the simulations are demonstrated. The proposed antenna is fed by 50 Ω probe feed. The results are presented in the form of input reflection coefficient (S_{11}) response, gain and radiation patterns.

The Proposed Antenna Structure

The generation process of the proposed antenna structure is composed of two steps. Thefirst step is to generatethe 1st iteration of the modified Peano pre-fractal curve as demonstrated in Figure 1(b). The straight line in Figure 1(a), (the initiator), has been replaced by the nine segment structure in Figure 1(b), the generator. The details of the generation process can be found in the literature [13].If the length of the initiator line is L_o, the length enclosed by any pre-fractal structure at the nth iteration n, L_n is [13]:

$$L_n = 2^n L_{n-1} \text{ for } n \geq 1 \qquad (1)$$

The second step is to use a meander line section superimposed on the horizontal line segments of the structure in figure 1(b) to produce the hybrid structure shown in Figure 1(c).

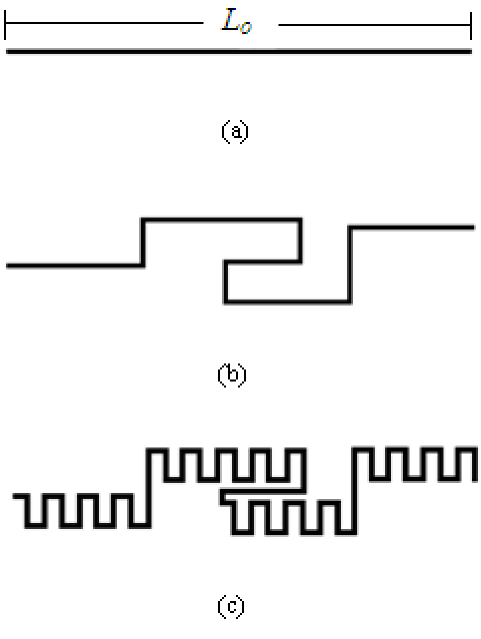


Figure. 1: The steps of growth of the proposed meander line superimposed on a Peano pre-fractal curve of the first iteration.

The Antenna Design

The three essential parameters to design a planar monopole antenna are:

- Frequency of operation (f_o): The resonant frequency of the antenna must be selected appropriately. The antenna should operate in 1.71 GHz to 2.01 GHz, the desired LTE frequency band and 5.0 GHz to 5.5GHz band.The obtained bands coveringthe frequency band 1.71 - 2.01 GHz which is already available as a study of current plan according to UMTS and LTE systems (band no.4) and wireless local area network (WLAN)standards (IEEE 802.11a band). Hence the designed antenna must be able to operate in these frequency ranges.

- Dielectric constant of the substrate (ε_r): The dielectric material selected for our design is Arlon Cu which has a dielectric constant of 2.33.
- Height of dielectric substrate (*h*): For the proposed antenna to be used in mobile terminals, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is selected as 0.9 mm.

Given specifications are:

1. Dielectric constant (ε_r) = 2.33
2. Height (h) = 0.9 mm.
3. Substrate width (W_g), W_g = 15 mm.
4. Substrate Length (L_g), L_g = 20 mm.

Modeling of the proposed antenna design has been carried out using Microwave Studio Suite of Computer Simulation Technology CST [21].Figure 2 shows the layout of the modeled antenna with respect to the coordinate system. The antenna is fed by a simple probe feed designed to have a characteristic impedance of 50 Ω.

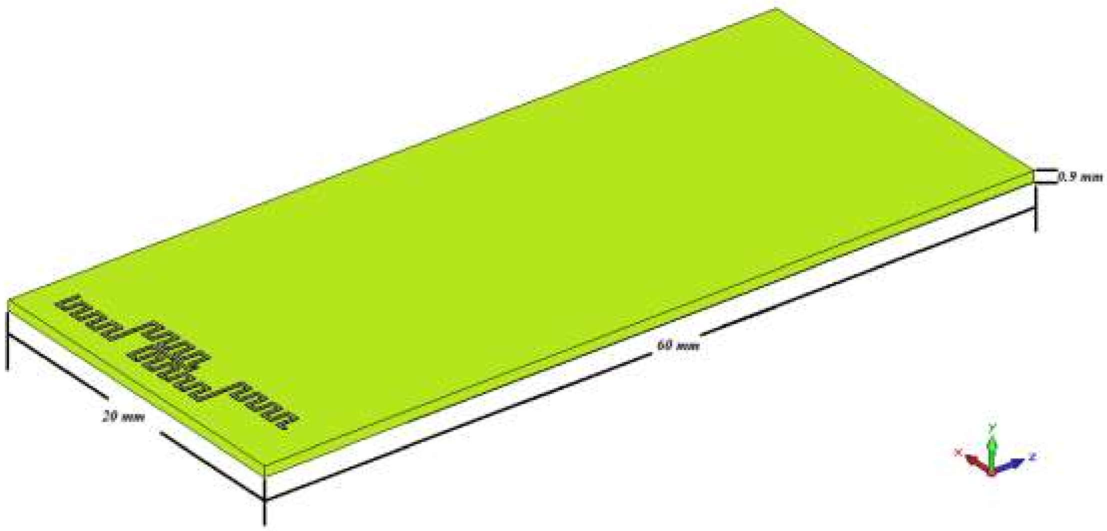


Figure. 2: The layout of the modeled antenna with respect to the coordinate system

The design process starts with converting the linear microstrip element into a curve based on Peano fractal geometry of first orderas illustrated in Figure 3. The performance evaluation of this antenna, in terms of the input reflection coefficient, has been carried out for a swept frequency range of 0-6 GHz, since most of the recently available communication services are allocated in their frequency range.

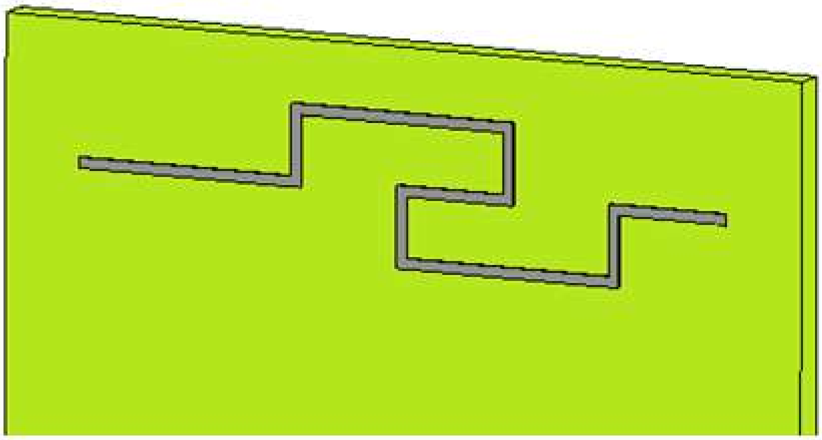


Figure.3: The modeled Peano fractal antenna of the 1st iteration

In this stage introducing a fractal shape of first order as shown in above figure, from the observation of results, one finds that the antenna offers dual-band resonant behavior. The lower resonant bandwidth, for $S_{11} \leq -10$ dB, starts from 1.9 GHz to 2.6 GHz and centered at about 2.35 GHz as shown in Figure 4. To a certain extent, these results support the findings of the work reported in [13].

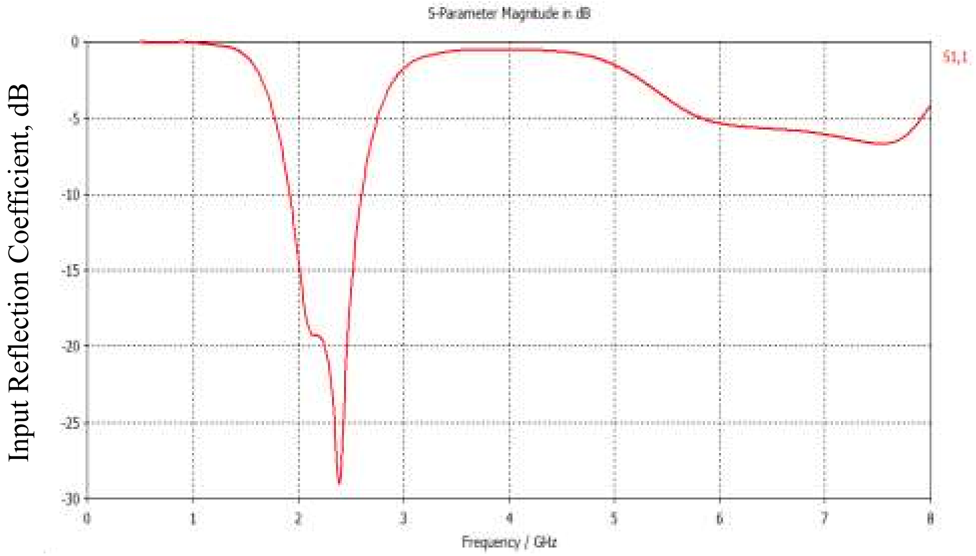


Figure. 4: Simulated input reflection coefficient of the proposed Peano fractal antenna of the 1st order iteration

Afterwards, the working to convert each horizontal line segment in the previous structure of Figure 1(b) and Figure 3 into form of meander line with multi teeth, to produce the structure shown in Figure 1(c) and Figure 5. Different simulation trials have been performed to reach the desired response, within the specified frequency range, as shown in Figure 6.

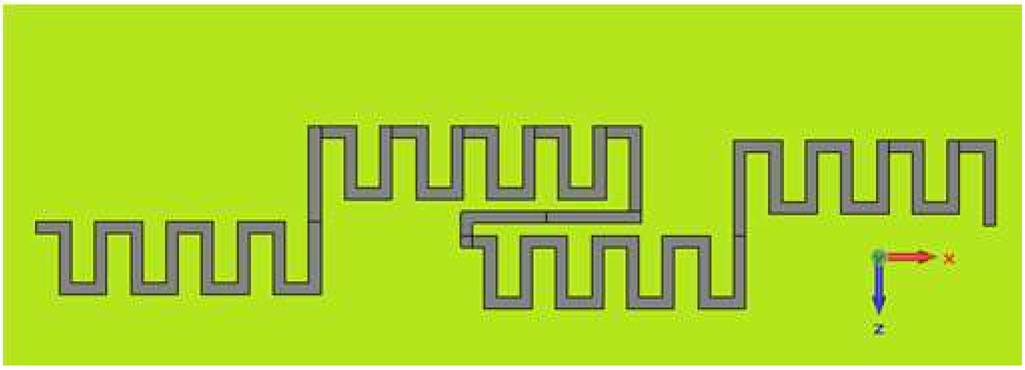


Figure. 5: The modeled structure of the combined Peano-meander line antenna

To explore the effect of varying the number of teeth included in the meander line sections, a parametric study has been conducted. Figure 6 and Table 1 summaries the resulting antenna input reflection coefficient response together with their corresponding number of teeth. To a certain extent, as the number of teeth increases, the resulting lower frequency decreases. This is attributed to the extra length included as n increases . After some range of n the f_{r1} suddenly increases to a higher value as compared to the preceeding ones.

This is because the fact that the inter-spacing between successive teeth becomes too small to be seused and considered as a continous surface without teeth. Consequntly the f_{r1} can be predicted according to this fact.

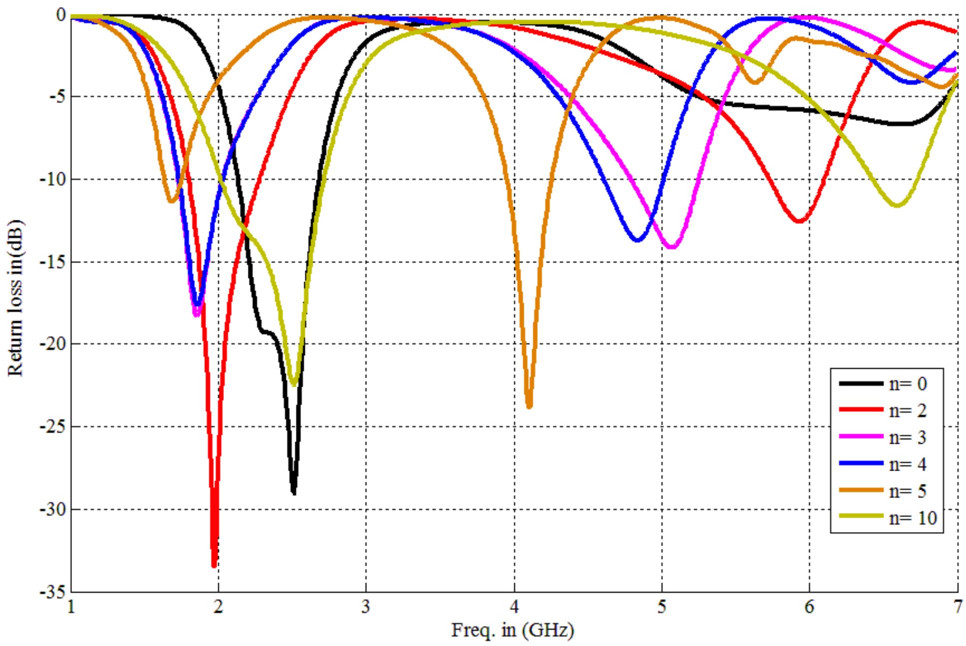
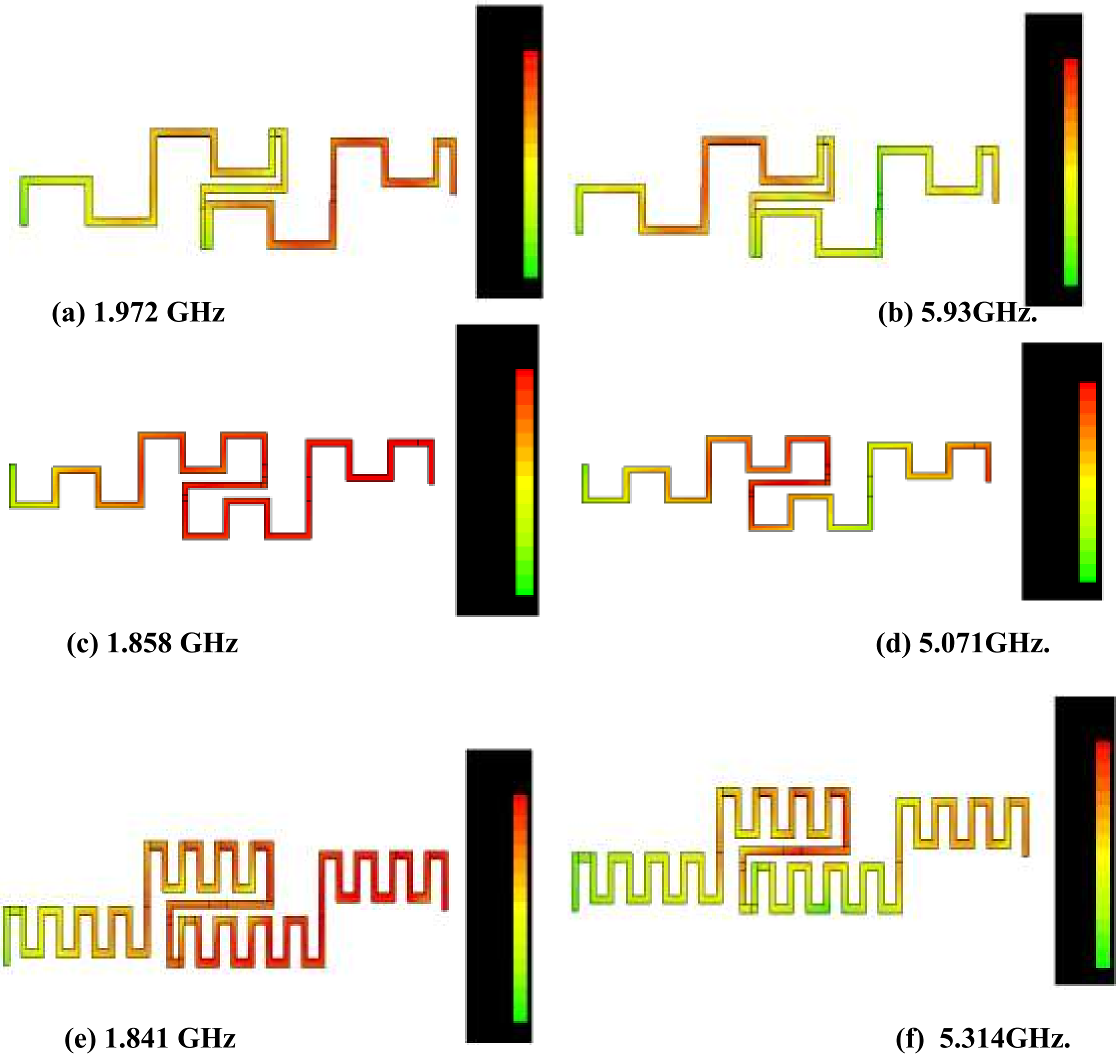


Figure. 6: Simulated input reflection coefficient response together with their corresponding number of teeth of proposed combined Peano-meander line antenna.

Table 1: Summary band frequencies and their corresponding number of teeth

No. of teeth	f_{r1} *(GHz)*	f_{r2} *(GHz)*	Guided wavelength, λ_g *(mm)*
2	1.972	5.931	88.59
3	1.858	5.071	105.71
4	1.841	4.842	106.68
5	1.685	4.144	116.56
10	2.5	6.600	78.56

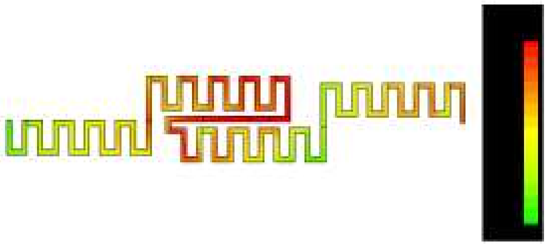


(a) 1.972 GHz **(b) 5.93GHz.**

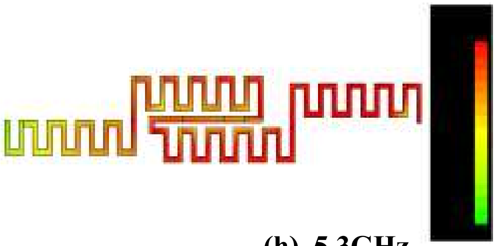
(c) 1.858 GHz **(d) 5.071GHz.**

(e) 1.841 GHz **(f) 5.314GHz.**

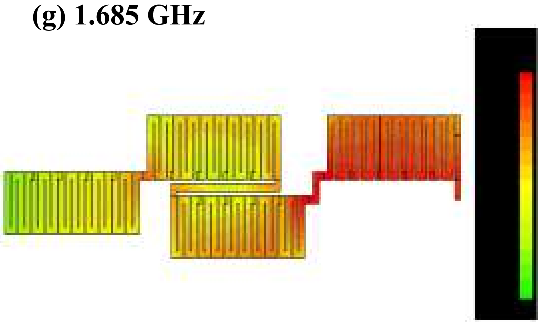
Figure 7: illustrates in details the current distributions at resonant frequencies Mentioned in Table 1



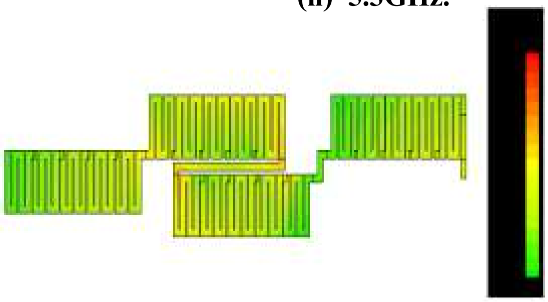
(g) 1.685 GHz



(h) 5.3GHz.



(k) 2.50 GHz



(l) 6.60GHz.

Figure 7 : Continued

The computed input reflection coefficient of this antenna is shown in Figure 8. The antenna resonates at two bands; the first resonant bandwidth is centered at 1.8 GHz and extending from1.71 GHz to 2.01 GHz which servesthe desired LTE frequency band. The second resonant bandwidth is centered at 5.3and extending from 5.0 GHz to 5.5GHz band (IEEE 802.11a band). However, this will not prevent the possibility of the existence of further resonances outside the swept frequency range.

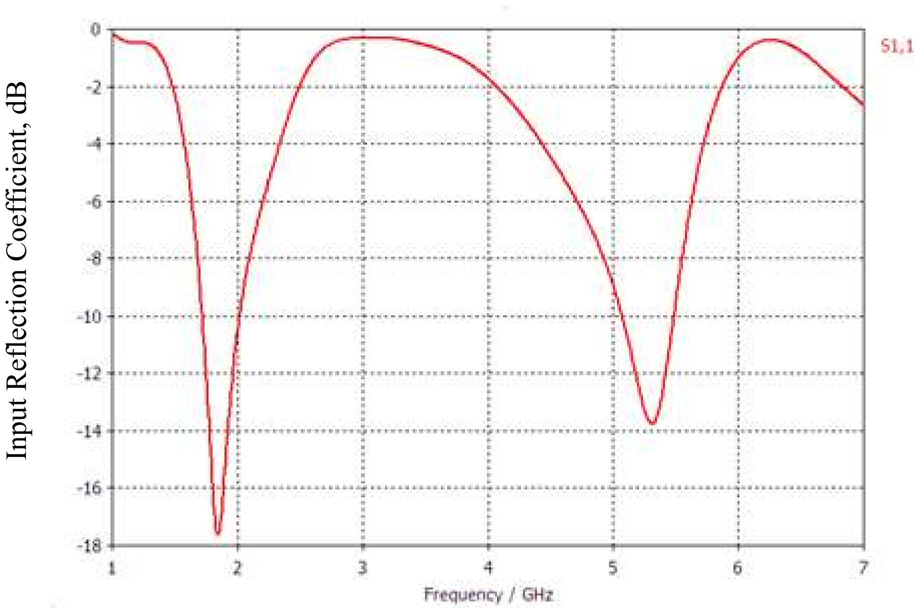


Figure.8: Simulated input reflection coefficient of the proposed combined Peano-meander line antenna.

Many conclusions have been extracted from the comparison of the computed responses shown in Figures 4 and 6 resulting from the antenna structures depicted in Figures 3 and 5 respectively. Keeping in mind that both antenna structures occupy the same length segment L_o as that of the initiator shown in Figure 1. The lower resonant frequency offered by the Peano based antenna is 1.90 GHz, while that offered by the combined Peano-meander line antenna is 1.71 GHz. This means that the proposed Peano-meander line antenna achieves further size reduction of about 20% as compared with the Peano fractal antenna. In terms of the frequency ratio of the upper to lower frequencies, the proposed antenna has a frequency ratio of about 2.95. To make use of the proposed antenna for a wide variety of communication applications, this ratio can be varied by controlling the number of the teeth in the meander line sections. This will provide the antenna designer more degrees of freedom.

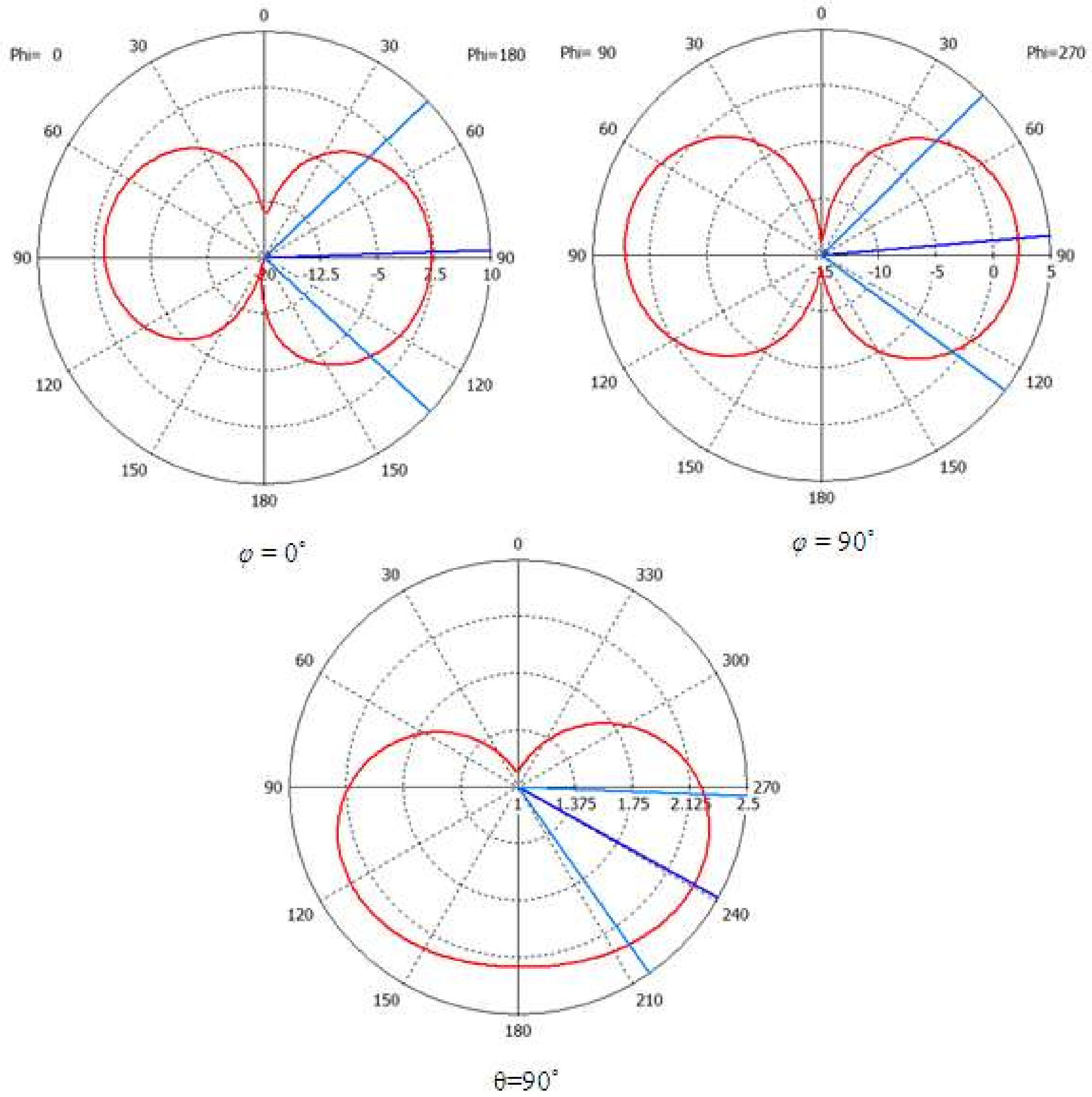


Figure.9: Simulated radiated power patterns at 1.8 GHz.

Figures 9 and 10 demonstrate the radiated power in elevation, at 1.8 GHz and 5.3 GHz respectively, for $\varphi = 0^{\circ}$, and $\varphi = 90^{\circ}$ planes and the radiated power in azimuth diagram for $\theta=90^{\circ}$. In simulation process, it has been noticed that the radiation pattern and operating frequency are varied according to feeding of antenna. Input reflection coefficient, radiation pattern, antenna efficiency, bandwidth and gain are important parameters of the designed antenna.

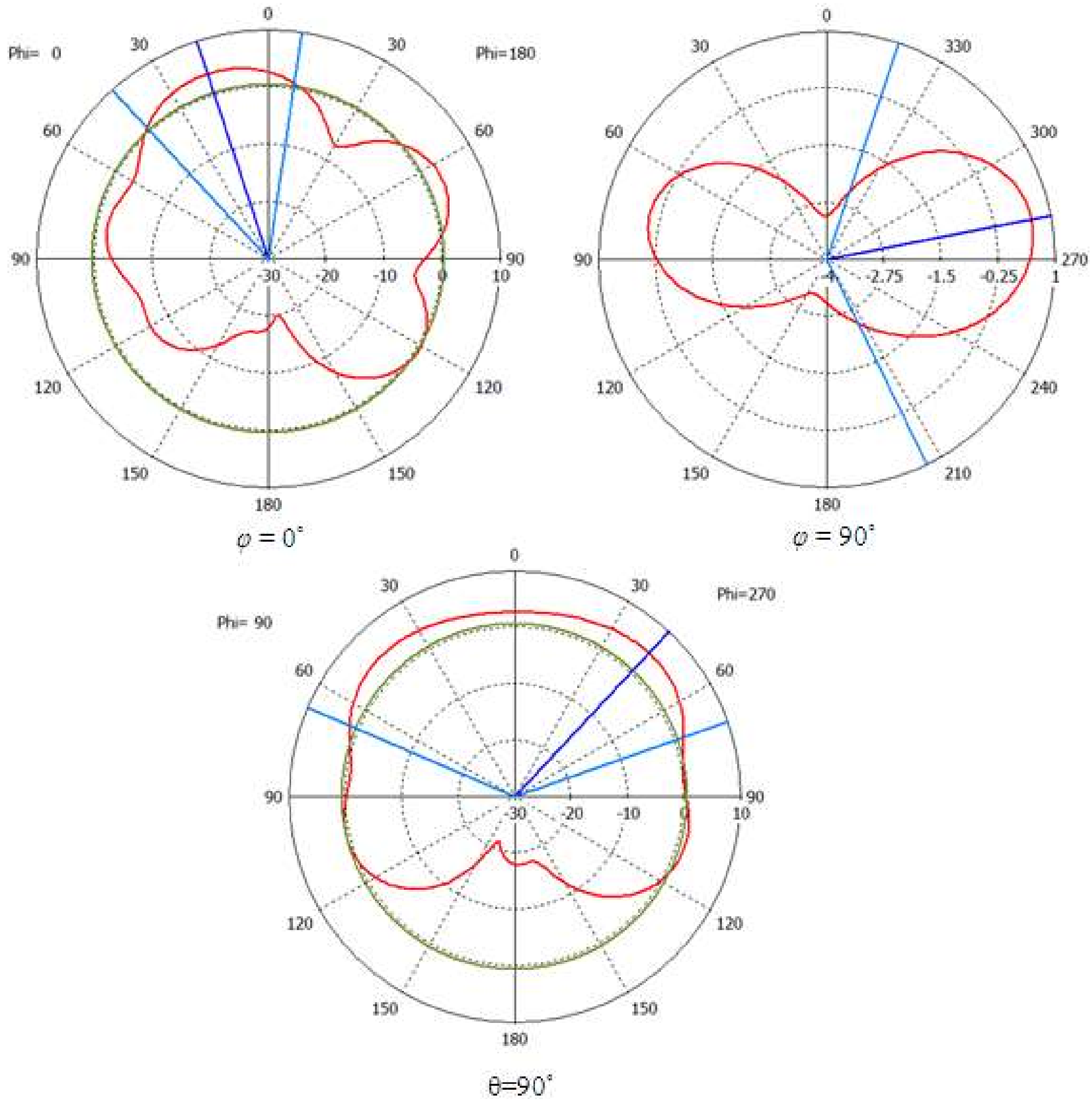


Figure.10: Simulated radiated power patterns at 5.3GHz.

Likewise, the antenna's reflection coefficient and gain, the directivity is also equally important in ourcase. For WLAN applications and LTE networks the directional antennas are deployed to focus the power in the desired direction. And to receive the actual power delivered by the directional transmitting antennas, the directional receiving antennas are required to be with good

gain, less reflections and high directivity. Since the LTE networks possess such antennas which have all the above mentioned parameters in a good agreement.
Similarly we have observed the directivity of planar monopole antenna at another frequency 5.3 GHz. It is cleared that the directivity and gain of any antenna are almost equal in magnitude when its efficiency is high.

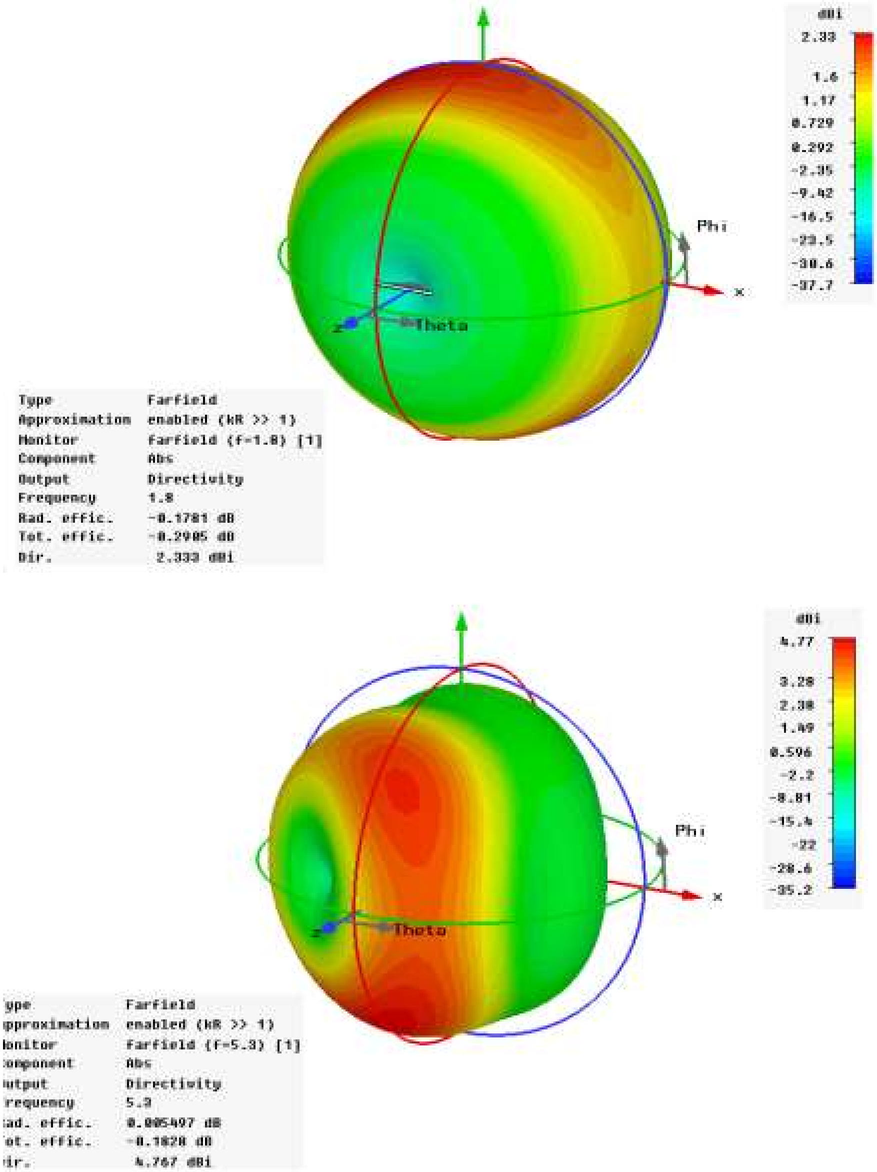
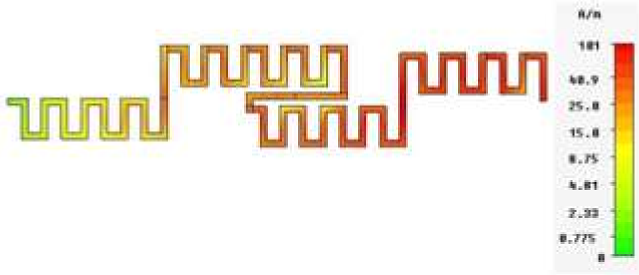
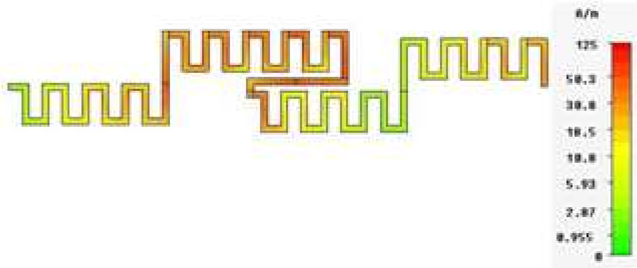


Figure.11: The directivities of the proposed antenna at: (a) 1.8 GHz, and (b) at 5.3GHz.

Figure 12 provides further in sight about the resonant behavior of the proposed antenna through the current distributions on its surface at the two resonant frequencies. It is clear from Figure 12(a) that at 1.8 GHz, the path length that contributes in the antenna radiated power is approximately equal to the antenna physical length. This is not true at 5.3 GHz as demonstrated in Figure 10(b); the antenna path length that contributes in the radiated power is shorter than that in the 1.8 GHz resonance. However, it seems logical that larger radiating length leads to lower resonant frequency and vice versa.



(a)



(b)

Figure.12: The current distribution on the surface of the proposed antenna at: (a) 1.8 GHz, and (b) at 5.3GHz.

CONCLUSIONS

A new combined fractal based microstrip antenna has been presented in this paper to be a candidate for use in LTE and WLAN applications. The proposed antenna structure is composed of a combination of a Peano fractal of the first iteration together with a meander line sections replacing the horizontal line segments of the Peano fractal geometry. Simulation results of the proposed antenna performance confirm that the antenna offers a further size reduction of about 20% as compared with an antenna structure that is composed of only fractal based structure using the same substrate.The results also reveal that the proposed antenna offers a ratio of the upper and the lower resonant frequency that is different than that offered by the Peano fractal based antenna. The possibility of varying this ratio makes the proposed antenna an attractive choice of antenna designers seeking for compact antenna for a wide variety of dual-band communication applications. Other radiation characteristics and gain at the two resonant bands of the proposed antenna are found reasonable to fulfill the requirements of the recently available communication services. The antenna operates in 1.71 GHz to 2.01 GHz in the desired LTE frequency band and 5.0 GHz to 5.5GHz band (IEEE 802.11a band) and gain of 2.155 dBi at the lower band and 4.772 dBi at the upper band.

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