New Compact Wideband Microstrip Antenna for Wireless Applications

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Abstract

In this paper, a miniature rectangular microstrip antenna over partial ground plane is presented by utilizing a space-filling property of fractal geometry in this design. It is simulated by High Frequency Software Simulator (HFSS) software, fabricated and tested by Vector Network Analyzer (VNA). Two types of slots are introduced in order to enhance antenna parameters such as bandwidth and return loss S1.1. This antenna is fabricated on FR4 substrate with a small size of (18 x 16 x 1.5) mm³, 1.5mm substrate thickness, 4.3 permittivity and 0.02 loss tangent. To feed this antenna, microstrip line feed is used. This antenna is implemented for wide bandwidth (4.8-11.6) GHz, and has three resonant frequencies at 5.5GHz, 8.3GHz and 10.7GHz with impedance bandwidth of 6.8GHz. The gap value g between partial ground plane and rectangular patch at top layer is optimized in order to achieve the optimal simulated return loss of (-46,-32 and -14) dB at three resonant frequencies (5.5, 8.3 and 10.7) GHz and optimal radiation efficiency of 93.42% with gain of 3.63dB. The simulated results have tolerable agreement with measured results. This antenna is suitable for wireless computer applications within C and X band communications.

1. Introduction

During last ten years, miniature size and inexpensive Micro Strip Antenna (MSA) has been evolved for different wireless communication applications such as handheld wireless devices and other computerized systems [1]. MSA is considered as a main reason for recent development in wireless communication technology [2]. For most antenna designers, MSA is an optimum option, because of its small size it can be easily mounted in communication devices [3]. It has an enticing attributes such as light weight, compactness, high efficiency [4], and compatibility with Integrated Circuit (IC) technology [4]. On the other hand, MSA has a narrow bandwidth [5]; there are several methods to overcome this problem, one of them by using fractal geometry [6]. Fractal geometry can be used to describe the occurrence of natural model that cannot be described by Euclidean geometry [7]. Fractal MSA is a design of MSA by using fractal technique that widely used for multiband and wideband applications in high data rate system [8]. Fractal has the main properties of space filling and self-similarity. Spaces filling can be used for MSA to increase the electrical length with longer surface current that makes the resonant frequency of MSA lower,

while self-similarity property can help in generating multiple resonant modes [9]. The shapes of fractal are varying such as Koch, Sierpinski, Peano, Tree, and Snowflake fractal antennas [10]. It comes into two main variances; the first one is random fractal component that constituted randomly from a set of non-determined steps such as tree shaped fractal antenna, while deterministic (chaotic) fractal or geometric fractal that has several copied, scaled down and rotated part of original shape such as Koch curve fractal antenna[11].

In [12], the researcher proposed a miniaturized Ultra-Wide Band (UWB) monopole microstrip antenna design by a combination of Giusepe peano and Sierpinski carpet fractals. This antenna is fabricated on FR4 substrate with dimensions of (20 x 25 x 1.6) mm³ and loss tangent of 0.02. The first iteration of Giusepe peano is applied at the edges of square patch with employing a Sierpinski carpet fractal on its surface, while semi elliptical ground plane is used with microstrip line feed as a feeding method. The results indicate a wide bandwidth (2.4-16) GHz, good gain, high radiation efficiency and omnidirectional radiation pattern. In [13], a miniaturization of fractal antenna using novel Giusepe peano geometry for wireless applications was proposed. This antenna is fabricated on FR4 substrate with dimensions (38.9) x 40 x 1.6) mm³, 4.4 permittivity and resonant frequency of 4GHz. The result shows that the first iteration has resonant frequencies of 3.61GHz, 6.20GHz and 8.43GHz frequency band. While the resonant frequencies of second iteration are 2.10GHz, 2.85GHz, 5.15GHz and 9.11GHz. There is reducing in the resonant frequency of second iteration, which means the miniaturization is achieved without change the dimension of antenna. This type of antenna is used for different wireless applications such as WLAN, Bluetooth and X band. On the other hand, in [14] the researcher introduced a Koch boundary based on square patch microstrip antenna. The right angled triangular Koch curve is formed on the edges of square patch for achieving multiband antenna. FR4 substrate is used in this design with dimensions (60 x 55 x 1.59) mm³ and permittivity of 4.4. The patch formation has been altered in several steps in order to realize antenna with multiband characteristic. This antenna resonates at several frequencies of 4.3GHz, 5.0GHz, 6.1GHz, 7.4GHz, 8.9GHz and 9.2GHz, by adding a circle in the middle of patch. A circular polarization has been obtained near resonant frequencies with satisfactory results of gain, bandwidth and VSWR. In [15], a monopole antenna for frequency reconfigurable wide to narrow band has been designed using slotted ground plane and it consists of microstrip slot antenna

and monopole antenna. The microstrip slot antenna exhibits three various frequency bands with resonant frequencies at (3.02, 3.89 and 4.56) GHz, while monopole antenna exhibits a wideband of (1.66-4.93)GHz. The copper strip and PIN diode has been used as switches and their effects are explained. There is a good agreement between simulation and measurement results in term of return loss and radiation patterns. On the other hand, a reconfigurable monopole antenna with a spiral-shape has been proposed in [16]. This antenna has been printed on substrate of FR4 with small size of (32 x 50.3 x1.8) mm³. Switches have been used in this antenna design in order to generate a number of resonant frequencies for various switches states. This antenna can cover many frequency bands such as ISM band within (2.4and 2.5)GHz frequency range Medical implant communication service band of (402-406)GHz. High agreement amid simulation and measurement results are existing which makes this antenna a worthy candidate for biomedical applications.

In this paper, miniature fractal MSA for wideband wireless applications has been tested. Four models are simulated by HFSS electromagnetic simulator. It is found that the best model that implies highest bandwidth consists of right-angled triangle boundary at left and right side of MSA with equilateral triangle boundary at top side of MSA and Giusepe Peano slot at the center of MSA. The best one has been fabricated, tested by Vector Network Analysis (VNA) and compared its simulation results with measured ones. All results are in good performance.

2. Micro Strip Antenna (MSA)

The traditional component of MSA is shown in Figure 1. It consists of the following layers: The top layer is metallic layer that can be made from gold or copper. It consists of two parts; the first part is called patch or microstrip that may take any form and the second one is called microstrip line feed that used as transmission line. This layer is photoetched on dielectric substrate [14]. The medium layer is called a substrate. FR4 type substrate is commonly used, because it is widely available in the market. Also, each substrate has a thickness h and permittivity E_r ; both are determined according to the type of substrate used and the range of permittivity should be within ($1.4 \le E_r \le 12$) range. MSA performance can be enhanced by controlling the substrate thickness h, therefore, it is considered as dominant factor for determining antenna electrical parameters. There is a relationship between thickness and permittivity; when thicker substrate is used with low value of permittivity, this makes antenna performance improved, but at the same time it has a disadvantage of increased dimension of antenna. Consequently, a compromise should be made between size and performance of MSA [17]. The bottom layer is called a ground plane layer. It may take any possible shape and it can be employed as either partial or full ground plane. It plays a crucial role to improve the bandwidth of MSA.

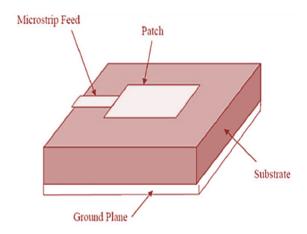


Figure 1: Components of MSA

3. Proposed Antenna Model

In this study, there are four different models are proposed for designing fractal MSA for wideband applications. The first model has rectangular MSA with Giusepe Peano boundary. The second model consists of rectangular MSA with Giusepe Peano slot at the centre to motivate a wideband characteristic. The third model has both Giusepe Peano boundary and Giusepe Peano slot at the center of rectangular MSA. The fourth model consists of right-angle triangle slot at the left and right side of MSA boundary with equilateral triangle shape slot at the top boundary of MSA and Giusepe Peano slot at the center to obtain antenna with higher impedance bandwidth than other models. All of four models are illustrated in Figure 2.

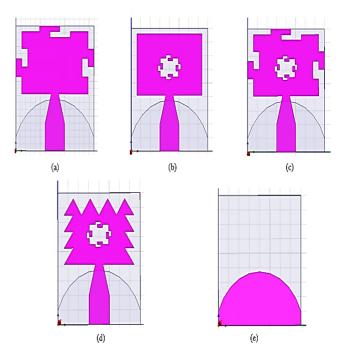


Figure 2: Different proposed models of Antenna (a) Model 1, (b) Model 2, (c) Model 3, (d) Model 4 (Top view) and (e) Model 4 (Bottom view)

The length (L_p) and width (W_p) of rectangular MSA (model 4) is calculated by using equations (1) to (5) [13], and they are adjusted to be 9mm and 13.6mm respectively.

$$W_p = \frac{c}{2f_r \sqrt{\frac{E_r + 1}{2}}} \dots \dots (1)$$

$$E_{reff} = \frac{E_r + 1}{2} + \frac{E_r - 1}{2} \left[1 + 12 \frac{h}{w} \right]^{\frac{1}{2}} \dots \dots \dots (2)$$

$$L_{eff} = \frac{c}{2f_r \sqrt{E_{reff}}} \dots \dots (3)$$

$$\Delta L = 0.412h \frac{(E_{reff} + 0.3)(\frac{w}{h} + 0.246)}{(E_{reff} - 0.258)(\frac{w}{h} + 0.8)} \dots \dots (4)$$

$$L_p = L_{eff} + 2\Delta L \dots \dots (5)$$

Where c is velocity of light in free space, h is substrate height, E_r is relative permittivity of the substrate, w_p is the width of patch, L_p is the actual length of patch, L_{eff} is effective length, E_{reff} is effective dielectric constant and ΔL is the extension dimension due to fringing field. The length of right-angle triangle slots at the left and right boundary of rectangular MSA is denoted by L_t , and at the same time it represents the height of equilateral triangle slot that can be calculated by:

Where L_t is equal to 2.25mm after applying above equation. The area of right-angle triangle slots at the left and right boundary of rectangular MSA denoted by A_r is calculated by equation (7):

$$A_r = \frac{1}{2} \left(L_t * \frac{w_p}{8} \right) \dots \dots (7)$$

The value of A_r is equal to 1.91mm^2 . Also, the area of equilateral triangle slots at the top side of rectangular MSA denoted by A_e is calculated by equation (8) and it equals to 3.82mm^2 :

$$A_e = \frac{1}{2} \left(L_t * \frac{w_p}{4} \right) \dots \dots \dots \dots (8)$$

The fractal Giusepe peano slot at the center of rectangular MSA is found by dividing the original rectangular MSA into nine small rectangles and cutting the center one only. Then, Giusepe Peano slots at all its sides up to first iteration are added in order to achieve an antenna with wideband characteristic. The initiator and generator of Giusepe Peano are shown in the figure below:



Figure 3: Giusepe Peano initiator and generator

The initiator length denoted by X can be confined by any Giusepe Peano pre-fractal curve for nth iteration form X_n . It is calculated by [18]:

$$X_n = 2^n X_{n-1}$$
 for $n \ge 1 \dots (9)$

The model 4 is fabricated on FR4 substrate. It has a rectangular shape of 18mm length and 16mm width. The partial ground plane consists of rectangle (3 x 18) mm² and semi-elliptical shape, both are combined together and covering the feedline with a gap g equals to 0.75 mm away from rectangular MSA. The feedline consists of two parts; the first one is rectangular shape with dimensions of (4×2) mm² and the second part is tapered rectangular shape with length of 4.23mm. Both of these two parts are combined together to form the feedline of rectangular MSA. The advantage of tapered feed line is to improve impedance matching. Also, the type of feeding used in this design is microstrip line feed. It is easy to fabricate with the simplest type of feeding methods. After optimization, the detailed dimensions of proposed antenna (model 4) are listed in Table 1. As well, the final geometrical view of proposed fractal MSA (model 4) is illustrated in Figure 4.

Table 1: The dimensions of Proposed Model 4

Parameter	Value	Parameter	Value
Permittivity E_r	4.3	Width of Rectangular MSA (patch) W_P	13.6mm
Thickness of substrate <i>h</i>	1.5mm	Length of rectangular Giusepe peano slot at top and bottom sides	1mm
Width of substrate W_s	18mm	width of rectangular Giusepe peano slot at top and bottom sides	0.4mm
Length of substrate L_s	16mm	Length of rectangular Giusepe peano slot at left and right sides	0.5mm
Width of ground W_g	18mm	width of rectangular Giusepe peano slot at left and right sides	0.84mm
Length of ground L_g	3mm	Gap between ground and patch g	0.75mm
Width of feed line W_f	2mm	Side length of right angle triangle slot <i>S</i>	2.88mm
Length of Rectangular MSA (patch) L_p	9mm	Length of right angle triangle slot L_t	3.4mm

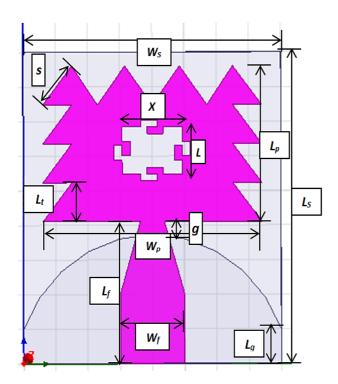


Figure 4: Geometrical view of model 4

4. Results and Discussion

Different models are investigated in order to obtain the best performance one. They have been designed and simulated by using Finite Element Method (FEM) based on HFSS simulator version 2014. A comparison between different models is listed in Table (2). From Table 2, it can be concluded that the model 4 (proposed model) is the optimum one. In accordance with it, the best return loss S1.1 are (-46, -34 and -14) dB at three resonance frequencies (5.5, 8.3 and 10.7) GHz with wide bandwidths among other models. So in that model, both of return loss S1.1 and bandwidth are enhanced that cannot be achieved by other models. While in model 1 that includes Giusepe Peano at boundary, the impedance bandwidth is 79% with adequate return loss values. The impedance bandwidth is increased remarkably at model 2 but the return loss S1.1 still somewhat keeps its previous values. In model 3, the impedance bandwidth is reduced with a small increase in return loss S1.1. So that, model 4 is the best choice. A comparison of return loss S1.1 at various values of frequency for different models is shown in Figure 5.

Table 2: Comparison of Proposed Model Based on Various Models.

Model	S1.1 (dB)	Resonance frequency (GHz)	Impedance bandwidth	Radiation efficiency	Gain (dB)
Model 1	-27.4, -16	5.3, 8.3	79%	94.59%	3.50
Model 2	-28.4, - 16.2, -14.2	5.4, 8.8, 10.8	85%	94.33%	3.68
Model 3	-31.2, -18.2	5.3, 8.3	75%	94.43%	3.57
Model 4 (Proposed)	-46, -32, - 14	5.5, 8.3, 10.7	84%	93.42%	3.63

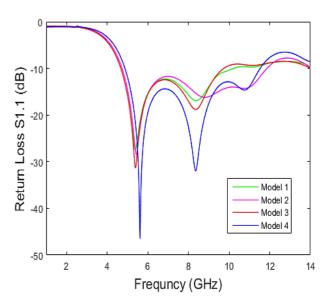


Figure 5: Simulated return loss S1.1 for various iterations number

Also, the proposed model 4 is simulated by changing the value of gap g to enhance the antenna parameters such as (bandwidth, return loss S1.1 and gain). It is clear that the gap value g is an adjusting factor to determine the optimal bandwidth of antenna. As shown in Table 3, it indicates the best value for g is 0.75mm. Because of that value, the best matching can be obtained between input impedance Zin and characteristic impedance of feed line that equals to 50Ω . A comparison of return loss S1.1 at different frequencies for different gap values is displayed in Figure 6.

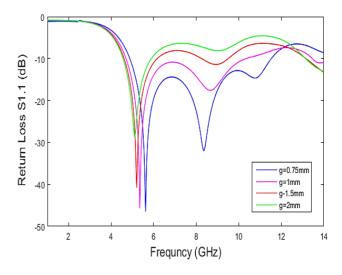


Figure 6: Simulated return loss S1.1 for different values of gap g

The Voltage Standing Wave Ratio (VSWR) of proposed model 4 is illustrated in Figure 7. It has a proper value at three resonance frequencies (5.5, 8.3 and 10.7) GHz that should be below or equal to 2. When the value of VSWR is higher than 2, it means there is a high mismatching between input impedance of antenna Zin and characteristic impedance of feedline. This makes the antenna will not work effectively. The input impedance Zin of model 4 reaches somewhat to characteristic impedance of feedline 50Ω at bandwidth range of (4.5-12) GHz.

Table 3: Comparison of Proposed Model Based on g.

g(mm)	S1.1(dB)	Resonance frequency (GHz)	Impedance bandwidth		Gain (dB)
0.75	-46, -32	5.5, 8.3, 10.7	84 %	93.42%	3.63
(proposed)	, -14				
1	-45.5,	5.3, 8.6	80.5 %	94.38%	3.48
	-17.5				
1.5	-40.5,	5.1, 8.9	31 %, 12 %	93.85 %	3.52
	-11.4				
2	-28.5	5	26 %	93.76%	3.43

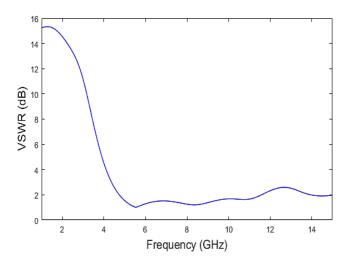
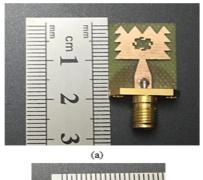


Figure 7: Simulated VSWR of model 4

After simulation of proposed model and getting the finest parameters values for designing fractal rectangular MSA that mentioned previously in Table (1). This proposed model is fabricated on FR4 substrate of (18 x 16 x 1.5) mm³ dimensions and tested by (VNA). The fabricated model is shown in Figure 8. A comparison between measured return loss of fabricated model with simulated return loss is presented in Figure 9.

The return loss S1.1 curve in Figure 9 indicates an acceptable discrepancy between simulated and measured results. The differences between them occur due to many reasons such as the effect of soldering and fabrication tolerance. Also, SMA connectors cannot implemented in HFSS software, but instead it uses microstrip line feed so that the difference between them may cause this simple disparity.



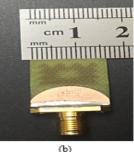


Figure 8: Fabricated prototype of proposed model (a) Top View (b) Bottom View

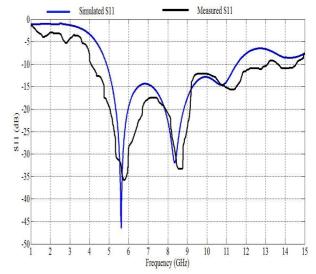
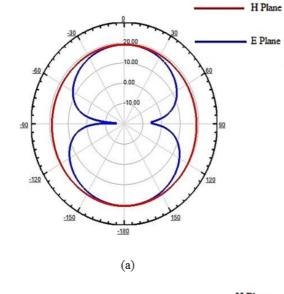
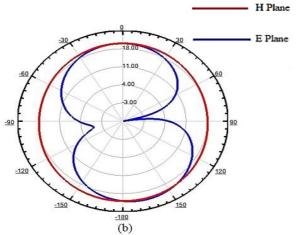


Figure 9: Simulated return loss as compared with the measurement

The 2D Radiation patterns of proposed model for three resonant frequencies are depicted in Figure 10, that point to far field radiation pattern at three resonant frequencies (5.5, 8.3 and 10.7) GHz. By taking two values of phi at 0 degree that represents XZ plane and at 90 degree that represents YZ plane, It is clear that the proposed model has a bi-directional radiation patterns and there is appearance of side lobe at higher resonant frequency of 10.7GHz





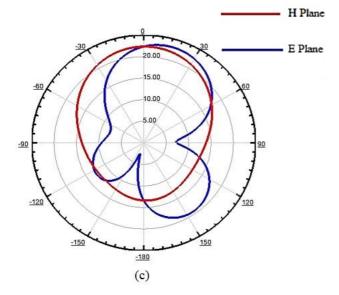


Figure 10: Simulated 2D Radiation Patteren at resonant frequencies of (a)5.5GHz ,(b)8.3 GHz, and (c) 10.7GHz

The gain of proposed model is presented in Figure 11, which points to gain for a frequency band (4-15) GHz. It is clear that the gain reaches the peak value at 11GHz that equals to 5.7dBi. Subsequently, it starts to decrease progressively.

In Figure 12, the 3D polar plot gain and directivity is illustrated. The values of gain at various resonant frequencies (5.5, 8.3, and 10.7) GHz is (2, 3.5 and 5.1) dB respectively. After acquiring the gain and directivity of proposed model, it is easy to find the radiation efficiency that can be calculated by [19]:

Radiation efficiency =
$$\frac{gain}{directivity} * 100\%$$
(10)

Accordingly, the amount of radiation efficiency is equal to 95% at 5.5GHz, 93% at 8.3GHz and 88% at 10.7GHz as illustrated in Figure 13.

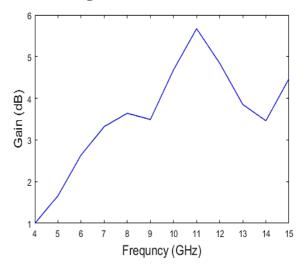
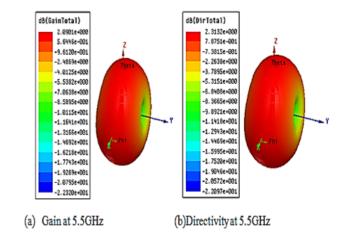


Figure 11: Simulated Gain versus frequency



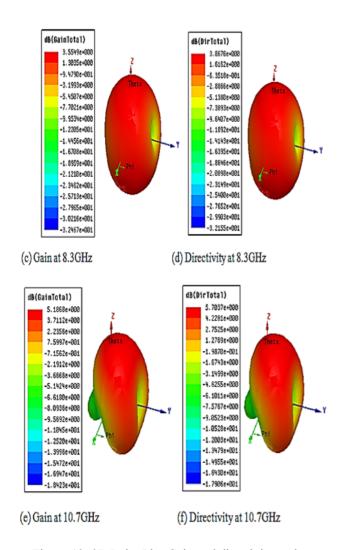


Figure 12: 3D Polar Plot Gain and directivity at three resonance Frequencies (5.5, 8.3 and 10.7)GHz

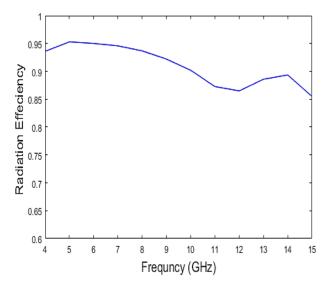


Figure 13: Radiation efficiency of proposed model

5. Conclusions

A new small size Fractal rectangular MSA has been proposed to operate at a bandwidth of (4.8-11.6) GHz. A comparison is made between four different proposed models that have been simulated by HFSS software. The best performance one was model 4; it has been optimized to get the optimum geomatric structure, fabricated and tested by VNA. Two types of slot are presented in this design in order to achieve both of wide bandwidth and improved return loss S1.1. These slots are etched on the top layer of MSA. It can be concluded that the first type of slot that has a shape of right angle triangle at left and right side of rectanglular MSA with equallitral triangle at the top, has advantage of reducing the return loss S1.1 value to -46 dB. Also, the second type of slot that has a shape of Giusepe Peano curve up to first iteration has advantage of increased bandwidth to 6.8GHz and miniature antenna size. The gap g value is optimized, and the best value is 0.75mm to acquire the widest bandwidth. The proposed model has a compact size of (18 x 16 x 1.5)mm³. The simulated return loss S1.1 has been valued to (-46, -32 and -14) dB and the fractional impedance bandwidth is 84%. The simulated results have tolerable agreement with measured results. The proposed model has a stable radiation patterns that make it suitable for wibeband applications within C and X bands. It can be integrated within many wireless computer networks as well as Intrnet of Things (IOT) utilities.

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