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Size Miniaturized Fractal Nested Circular Rings-Shaped Microstrip Antenna for Various Wireless Applications

Abstract-*In this paper; a wideband fractal circular rings shaped microstrip antenna over partial rectangular ground plane is presented. Fractal geometry technique is used in order to take advantage of its self-similar property which lead to attain not only size miniaturization but also wider bandwidth and iteration method is utilized that reach up to third iteration. The proposed model is simulated by High Frequency Structural Simulator (HFSS) package. Such model is designed on FR4 substrate with a compact size of (20×18×1.5) mm^3, 4.3 permittivity and 0.02 loss tangent. The microstrip line feed is used to feed this antenna with a length of 4.65mm and width of 3mm, in order to increase the impedance bandwidth of proposed model to 67.64%. This model is designed to operate at a range of frequency (4.5-9.1) GHz with two resonant frequencies at 5.6GHz and 8GHz. The length of ground plane L_g is optimized for enhance antenna parameters such as input reflection coefficient and Bandwidth. The simulation results show that the input reflection coefficient values are -54.5 dB and -46.5 dB at two resonant frequencies 5.6GHz and 8GHz. Also, radiation efficiency of proposed antenna is 97.29% with peak gain of 4.34dB. This antenna is appropriate for various wireless Applications such as satellite communication, weather radar, (Industrial Scientific Medical) ISM band and (Wireless Fidelity) Wi-Fi.*

Keywords- *C-band; Fractal MSA; HFSS; nested circular rings; rectangular partial ground plane.*

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1. Introduction

Day by day, recent communication systems are become more vigorous and compact. Therefore, increased demands for small size and wideband Micro Strip Antenna (MSA) [1]. This increases attention comes from the development in handheld wireless devices such as mobile phone, computers and navigation system [2]. MSA has many fascinating features such as size compactness, cheap, low profile, lightweight and easy fabrication process [3]. On the other hand, it has a drawback of narrow bandwidth [4]. To address this problem, many researches have been made to develop several impedance bandwidth enhancement techniques of MSA with keep it size as small as possible [5]. Fractal geometry has advantage of small size and wideband or multiband behavior [6]. It has two important properties that can be utilized to design different type of MSA and microwave circuits that are space filling and self-similar property [7]. Fractal geometry has many known types are Sierpinski gasket, Sierpinski carpet, Koch curve, Hilbert curve and Minkoski [8,9]. Many researchers have been focus on fractal MSA, they proposed many different types of fractal such as in [10], the researcher proposed slot antenna with using fractal Sierpinski geometry to enhance the bandwidth. Substrate of FR4 (70*70*1.6) mm^3 with permittivity of 4.4 is utilized in the antenna design. Microstrip line feed is used to excite the antenna and it added on ground layer. The simulation results indicate that the impedance bandwidth is 35.3% at two resonant frequencies of 2.3GHz and 2.9GHz with input reflection coefficient below -10dB. Also, the researcher of [11] suggests a wideband monopole antenna with heptagonal-shaped using fractal geometry to obtain wideband response and smaller size. Coplanar waveguide feed is used to excite this antenna, RT/Duroid substrate is used (20×25×1.6) mm^3 with permittivity of 2.2. As the number of iterations increases, the bandwidth will increase until reach 4th iteration. The obtained bandwidth is equal to 10.3GHz with 10GHz center frequency f_c, and omnidirectional radiation pattern with good gain of 5.3dB. On the other hand, in [12] the researcher

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proposed a multiband and wideband planar antenna for WLAN and WiMAX applications, this antenna consists of a circular patch with two rectangular slits and an inverted U-shaped slot at the top layer of MSA. A partial ground plane with hexagonally shaped slot is used to improve impedance bandwidth of the antenna. FR4 substrate is used (39×25×1.59) mm^3 with permittivity of 4.4. Simulation results indicate that this antenna has a broad operating bandwidth with three resonant frequencies at 2.4GHz, 3.2GHz and 5.6GHz, and omnidirectional radiation pattern.

This research is attempted to design a fractal nested circular rings MSA that achieve both of wide bandwidth and size miniature depending on iteration method up to the third iteration. Additional techniques are used such as rectangular shaped partial ground plane and fractal geometry technique to obtain optimum bandwidth; optimization is made for length of ground L_g in order to enhance antenna parameters such as input reflection coefficient and bandwidth.

2. The Microstrip Antenna (MSA) Structure

The components of MSA is shown in Figure 1 which comprise of three layers, the first one is a thinning metallic strip that place above a dielectric substrate, it is called patch or microstrip and may take any shape of circular, rectangle, square, elliptical and triangular design. The thickness of patch layer t is very thin and it has a negligible effect on the performance of the antenna. To calculate the length L and width w of the patch that has a shape of square or rectangle there are specific equations can be applied. The second layer is dielectric material or substrate that placed between patch and ground plane. There are many types of substrate materials; the thickness of substrate h has a fundamental role for determine antenna performance. Also, each type has a specific value for permittivity and loss tangent. In order to obtain a wide bandwidth antenna it must use a thicker substrate with low permittivity value, but it increases the dimension so that a compromise should be made between the size of the antenna and its performance. The final layer is a ground plane layer it is a metallic layer that has a vital role for determining wideband or multiband response, and it can be used as partial or etching slot inside it to obtain some specific characteristic [13].

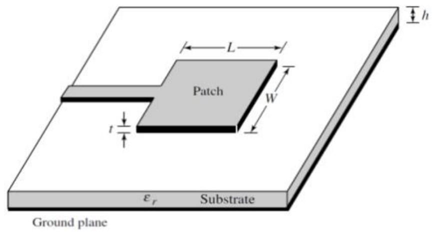


Figure 1: Components of MSA

3. The Proposed Antenna Structure

The proposed model is implemented by using iteration method up to 3rd iteration. It found that when determining the iteration number more than 3, the bandwidth of MSA is not enhanced, also, it increases the complexity of manufacturing process. Initially, the microstrip (patch) has a circular base shape with a radius R_1, which can be calculated by equation (1) [13]:

$$R_1 = \frac{f}{\left\{1+\frac{2h}{\pi \epsilon_r f}\left[ln\left(\frac{\pi f}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad (1)$$

Where h is thickness of substrate, ϵ_r is a permittivity, f is a resonant frequency. In this design there are two resonant frequencies, first resonant frequency F_{r1}, second resonant frequency F_{r2} and center frequency f_c are 5.6GHz, 8GHz and 6.8GHz respectively. The frequency f calculated by Eq. (2) [13]:

$$f = \frac{8.791*10^9}{f_c\sqrt{\epsilon_r}} \quad (2)$$

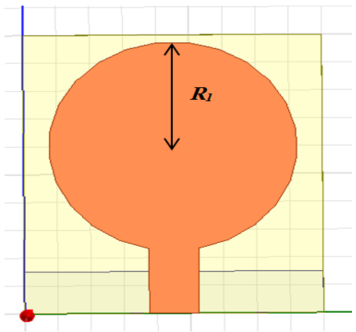
Also, the center frequency $f_c$can calculate by Eq. (3) [13]:

$$f_c = \frac{F_{r1}+F_{r2}}{2} \quad (3)$$

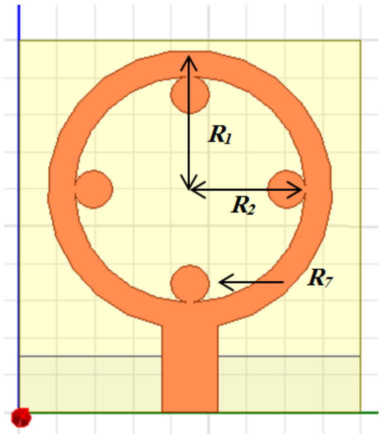
Applying equations (1), (2) and (3) with ϵ_r =4.3 and h=1.5mm, the radius R_1 of the circular base of the proposed model is equal to 7.5mm as shown in Figure 2 (a). It also represents the external radius of the outer ring while the internal radius of the ring R_2 equal to 5.6mm can be calculated by Eq. (4):

$$R_{(i+1)} = \frac{3}{4} R_i \quad (4)$$

Where i=1, 2, 3, 4, 5. Then four small circles with radius of R_7 is added inside the first ring as shown in Figure 2 (b), the value of R_7 assumed to be 1mm in order to generate the first iteration.



(a)



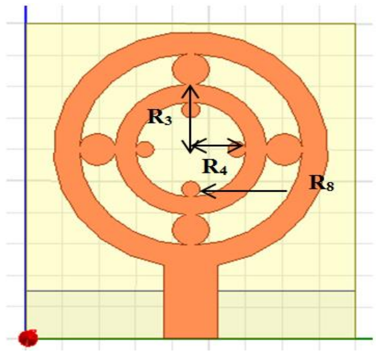
(b)

Figure 2: (a) Base, (b) First iteration

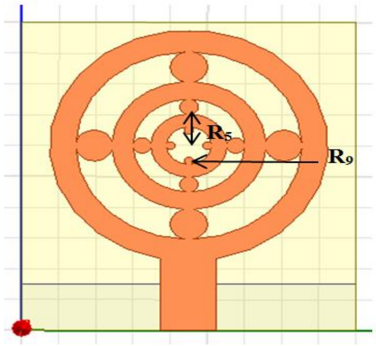
The second step includes adding another circular ring with the external radius of R_3 which equal to 3.75mm calculated by Eq. (4). Also, the internal radius of the second circular ring R_4 equal to 2.8mm that calculated by Eq. (4), both external and internal radiuses constitute the second circular ring as shown in Figure 3(a) that represent the second iteration. Also, the radius of four circles R_8 that added at different sides inside the ring equal to 0.5mm is calculated by Eq. (5):

$$R_j = R_i \times S \quad (5)$$

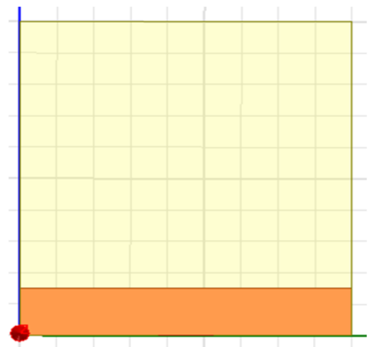
Where i = 7, 8 and j =8, 9, also, S is a scale factor of 0.5. In third step another circular ring is etched with external radius R_5 equal to 1.87mm which calculated by Eq. (4) and the internal radius of the ring R_6 equal to 1.4 calculated by Eq. (4) in order to form the third circular ring as shown in Figure 3(b). Also, four smaller circles with radius of R_9 is added at four sides and the value of R_9 equal to 0.25mm calculated by Eq. (5). A partial rectangular ground plane is used for enhancing the impedance bandwidth of proposed antenna as shown in Figure 3(c). The type of substrate used is FR4 (20×18×1.5) mm^3, the gap between the top layer of circular-shaped MSA and ground plane layer is equal to 1.65mm. In addition, microstrip line feed is the type of feeding used to excite this antenna; it is the simplest type of feeding method. The parameters of proposed antenna are summarized in Table 1. Finally, the geometrical view of the proposed antenna is shown in Figure 4.



(a)



(b)



(c)

Figure 3: (a) Second iteration, (b) Third iteration (c) Back view

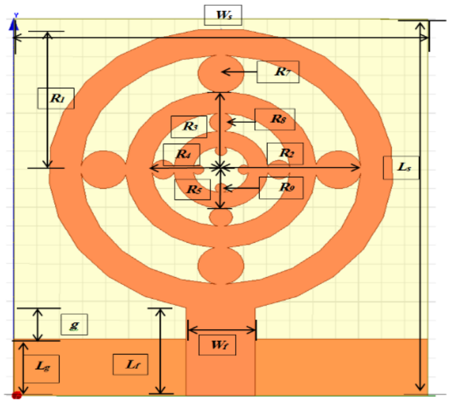


Figure 4: Geometrical view

Table 1: The parameters of proposed model

Parameter	Value (mm)	Parameter	Value (mm)
Permittivity ϵ_r	4.3	External radius of first ring R_1	7.5
Thickness of substrate h	1.5	Internal radius of first ring R_2	6.1
Loss tangent	0.02	External radius of second ring R_3	4.1
Operating frequency f_c	6.8 GHz	Internal radius of second ring R_4	3
Width of substrate W_s	18	External radius of third ring R_5	2
Length of substrate L_s	20	Internal radius of third ring R_6	1.2
Width of ground W_g	18	Gap between ground and patch g	1.65
Length of ground L_g	3	Radius of first circle R_7	1
Width of feed line W_f	3	Radius of second circle R_8	0.5
Length of feed line L_f	4.65	Radius of third circle R_9	0.25

4. Simulation Results

The proposed model has been designed and simulated by using Finite Element Method (FEM) based on HFSS (version 14.0) software package.

I. The Results of Input Reflection Coefficient (S11)

Three iterations were implemented to achieve wideband behavior. After each step of iteration, the area of outer circular ring equal to 59.78mm 2 will be reduced by 2.5times the inner circular ring until it reaches 8.5mm^2 for third or (inner) circular ring. A comparison between the results of various iterations is summarized in Table 2.

In addition, input reflection coefficient (S11) comparison at various frequencies for different iteration numbers is shown in Figure 5.

It is clear that the lower and higher frequency of operating band for base, 2nd and 3rd iteration are almost the same, also the lower and higher resonant frequency are slightly affected by change iteration number while the lower and higher frequency of operating band is greatly affected when change iteration number to 1st iteration with an evident change in resonant frequency. It is obvious that at 3rd. iteration, it can achieve the best-input reflection coefficient values that equal to (-54, -46.5) dB at two resonant frequencies (5.6, 8) GHz among other iterations. There is a clear difference between 2nd and 3rd iterations of proposed antenna as shown in Figure 5 which imply a good enhancement in the values of input reflection coefficients form (-34.8, -31.7) dB to (-54.5,-46.5) dB, which lead to enhance impedance matching. In addition, the effect of change the ground plane length L_g on the performance of the proposed model is summarized in Table 3. Initially, the ground plane length is taken 2mm and increasing by 0.5mm until reach 4mm. It is clear that there is a slight change in impedance bandwidth while the input reflection coefficient (S11) values are changed dramatically especially when L_g equal to 3mm, therefore the best value for ground plane length L_g is 3mm. As well, input reflection coefficient (S11) comparison at various frequencies for various values of L_g is shown in Figure 6.

Table 2: A comparison of proposed model based on various iterations no

Iteration no.	S11 (dB)	f_r (GHz)	BW	Radiation efficiency	Gain (dB)
Base	-36, -26.5	5.8, 7.7	68.14%	97.44%	3
1st	-47	4.6	30.43%	90.54 %	3.5
2nd	-34.8, -31.7	5.5, 7.9	67.16%	97.38 %	3.14
3rd (proposed)	-54.5, -46.5	5.6, 8	67.64%	97.29 %	3.12

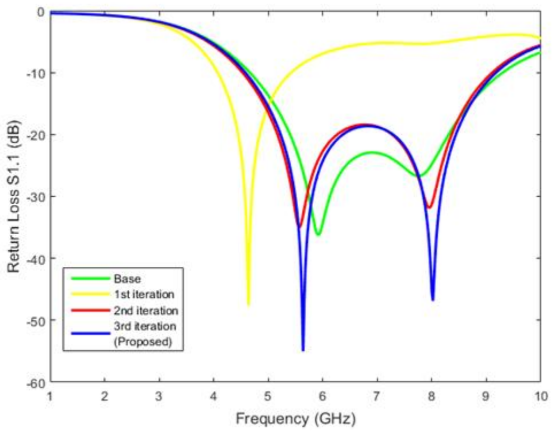


Figure 5: Simulated input reflection coefficient (S11) for various iterations no

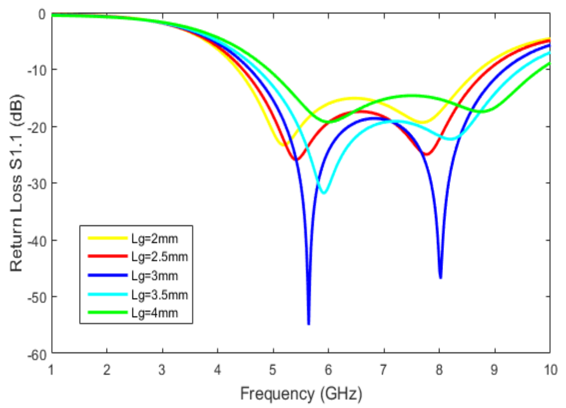


Figure 6: Simulated input reflection coefficient (S11) for various values of length of ground L_g

The simulated input reflection coefficient (S11) curve of the proposed antenna after optimization is shown in Figure 7; it has two perfect values at -54.5dB and -46.5dB for two resonant frequencies at 5.6GHz, 8 GHz with impedance bandwidth 67.64%.

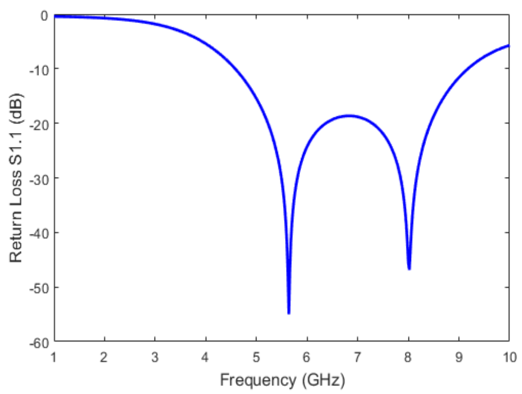


Figure 7: Simulated input reflection coefficient (S11) of the proposed model

The input impedance of proposed model *Zin* is illustrated in Figure 8, it observes that input impedance *Zin* is close to 50Ω characteristic impedance of feed line at a range of frequency (4.5-9.1) GHz. In addition, the simulated Voltage Standing Wave Ratio (VSWR) of proposed model is shown in Figure 9, it has excellent values at two resonant frequencies (5.6, 8) GHz that lied below 2.

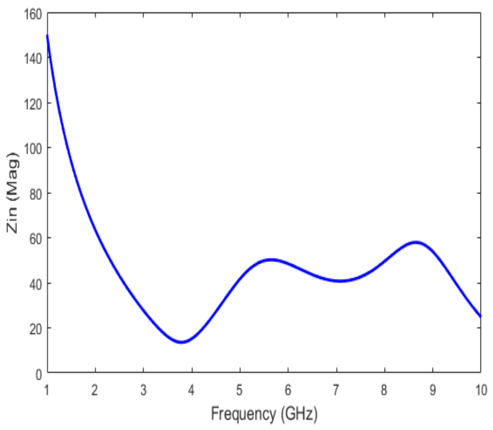


Figure 8: Simulated input impedance *Zin* of the proposed model

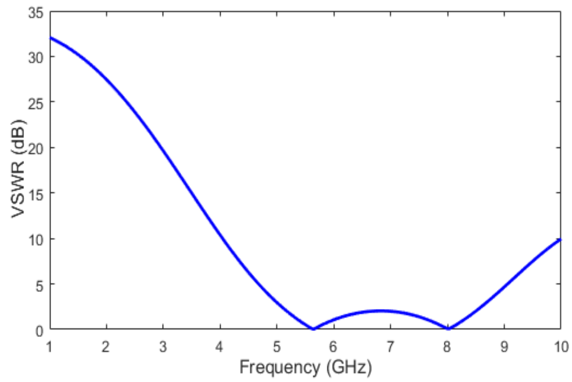
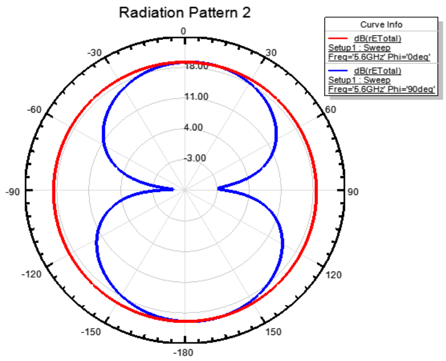


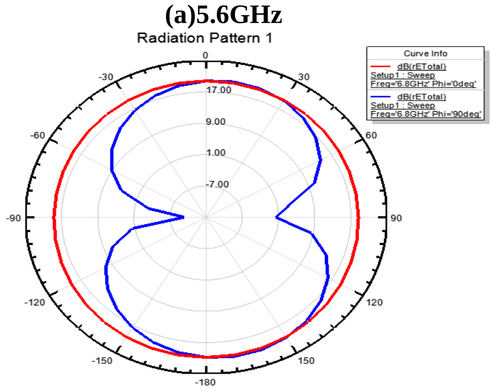
Figure 9: Simulated VSWR of the proposed model

II. The Results of Radiation Pattern

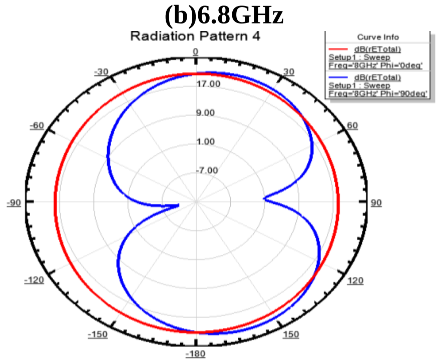
The radiation pattern is a graphical representation of the power radiated by the antenna, the 2D Radiation pattern of proposed antenna for two resonant frequencies (5.6, 8) GHz is shown in Figure 10. It is clear that the proposed antenna has a bi- directional radiation pattern and these radiation patterns are almost stable. In addition, E-plane obtained when ϕ equal to 90deg represented by blue color curve while H-plane obtained when ϕ equal to 0deg represented by red color curve.



(a)5.6GHz



(b)6.8GHz



(c)8GHz

Figure 10: Simulated 2D radiation patterns at two resonant frequncies (5.6GHz, 8GHz) and center frequency at 6.8GHz

The gain versus frequency plot shown in Figure 11, which indicates the gain for a frequency range of (4-10) GHz, it is clear that the gain begins to increase gradually from 4.5GHz until reach peak value of 4.34dB at 9GHz, and then it starts to decrease. The 3D polar plot gain and directivity is shown in Figure 12, the gain value is 2.23dB at a resonant frequency 5.6GHz, and 4.03dB at resonant frequency 8GHz. Radiation efficiency can be found from gain and directivity values and is calculated by Eq. (6) [14]:

$$\text{Radiation efficiency} = \frac{gain}{directivity} \times 100\% \qquad (6)$$

Therefore, radiation efficiency equal to 96% at 5.6GHz and 95% at 8GHz, as illustrated in Figure 13.

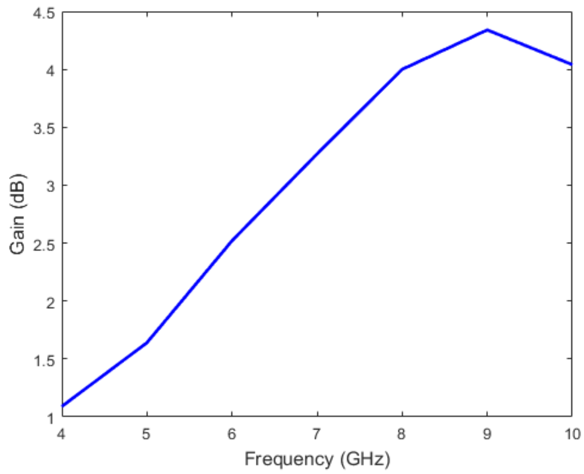
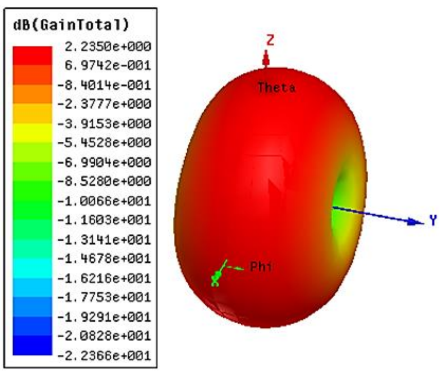
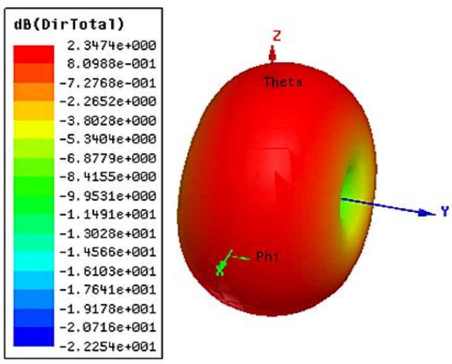


Figure 11: Simulated gain versus frequency



(a)Gain at 5.6GHz



(b) Directivity at 5.6GHz

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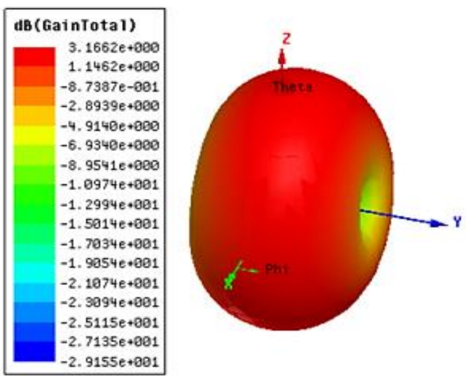
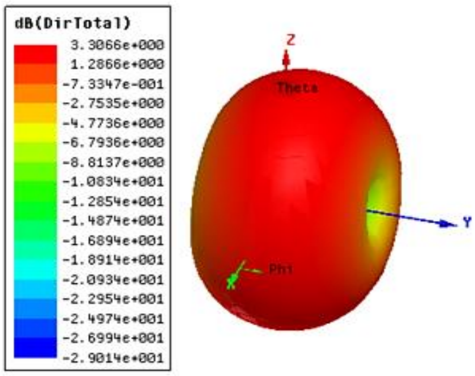
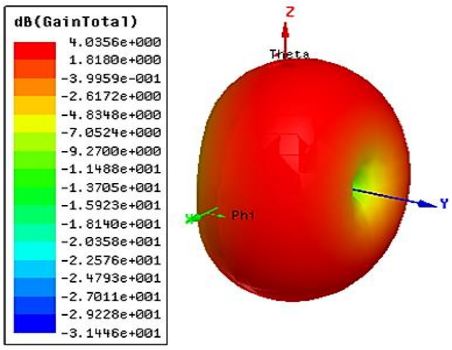


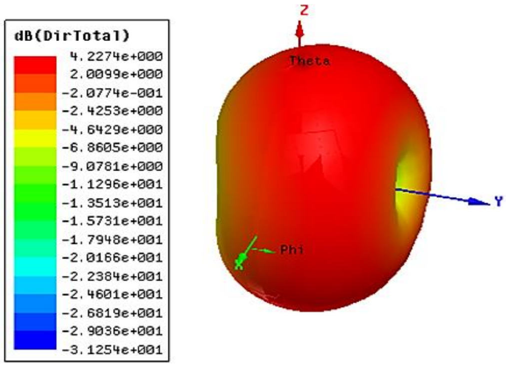
(c)Gain at 6.8GHz



(d) Directivity at 6.8GHz



(e)Gain at 8GHz



(f) Directivity at 8GHz

Figure 12: 3D Polar plot gain and directivity at various frequencies

Table 3: A comparison of the proposed antenna with other references

Ref. no	S11 dB	f_r GHz	Frequency ranges (GHz)	Peak gain dB	Size of antenna
[10]	-30, -15.5	2.3 , 2.9	(2-3.6)	3.8	(70×70×1.6)mm^3
[11]	-21	5.5, 10, 14	(4.7-16.7)	5.3	(20×25×1.6) mm^3
[12]	-13, -22.5, -27.5	2.4, 3.2, 5.6	(2.4-2.48), (3.3-3.7) and (5.15-5.875)	5.6	(39×25×1.59)mm^3
This work	-54.5 ,-46.5	5.6, 8	(4.5-9.1)	4.34	(20×18×1.5)mm^3

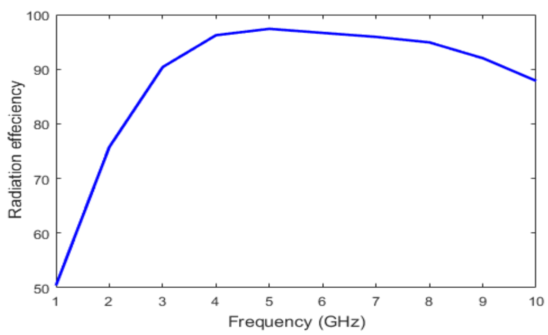


Figure 13: Radiation efficiency of the proposed antenna

5. Comparison with Other References

As compare the results of proposed antenna with the other model of [10-12]. The results of the comparison are listed in Table 3, it indicates that the proposed antenna has the smallest size among other references which equal to (20×18×1.5)mm^3 and better input reflection coefficient (S11) which equal to (-54.5 and -46.5) dB for a range of frequencies between (4.5-9.1)GHz. That meets the demands for size miniature antenna in modern wireless communications systems.

6. Conclusion

A new minaturized circular rings-shaped Fractal MSA has been proposed to operate at a wide bandwidth of 4.6GHz. In this design, an iterative method is based that reach up to the third iteration. The proposed antenna has a compact size of (20×18×1.5) mm^3, and designed on FR4 substrate with 4.3 permittivity and 0.02 loss tangent. Rectangular shaped partial ground plane is used in order to achieve wider bandwidth. Also, the length of ground L_g is optimized, and it found that when L_g equal to 3mm and W_f equal to 3mm the best input reflection coefficient (S11) values and wide bandwidth are accomplished. The simulated results indicated an excellent input reflection coefficient (S11) values of (-54.5, -46.5) dB and VSWR≤ 2 at two resonant frequencies of 5.6GHz and 8GHz. Eventually, the similarity of radiation patterns of the proposed antenna makes it suitable for various wireless Applications such as satellite communication, weather radar, ISM band and Wi-Fi.

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