# Miniaturized Wideband Microstrip Antenna for Recent Wireless Applications

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### Abstract

In this paper, a pentagon slot inside fractal circular patch microstrip resonator to design compact antenna over partial ground plane is introduced using 3rd iteration of adopted fractal geometry. This antenna is modeled on FR4 substrate with a size of (20 x 18) mm$^2$, thickness of 1.5mm, permittivity of 4.3 and loss tangent of 0.02. The used type of feeding is microstrip line feed. It is designed to operate at wide frequency range of (4.5-9.3) GHz at resonant frequencies of 5.7GHz and 7.9GHz with impedance bandwidth of 4.8 GHz. Both lengths of ground plane $L_g$ and width of feed line $W_f$ are optimized in order to acquire optimum bandwidth. The simulated return loss values are -33 and -41 dB at two resonant frequencies of 5.7 and 7.9 GHz with gain of 3.2 dB. The simulated results offered acceptable compatibility with measured results. Also, the proposed wideband microstrip antenna has substantial compactness that can be integrated within numerous wireless devices and systems.

***Keywords***— Fractal microstrip antenna; pentagon slot; C-band; Partial ground plane; compactness.

## 1. Introduction

Recently, wireless communication system has testified enormous expansions and augmentation in the request for high data rate through wide bandwidth, consequently Micro Strip Antenna (MSA) is used to meet that demand [1]. There are a large number of MSAs developed for indoor and outdoor communications and Radar applications [2]. The most important features of MSA that considered as challenge for researchers are size compactness, ease of fabrication, low cost and light weight. Also, it can be simply incorporated on Printed Circuit Board (PCB) [3]. However, MSA has drawbacks of narrow bandwidth and low gain. Thus, the shape of MSA needs to be changed by using a fractal geometry technique [4]. Fractal MSA is principally used to improve the antenna electrical parameters such as bandwidth, input reflection and gain in addition to size reduction [5]. The form of fractal MSA seems either random or deterministic. Random fractal is constituted randomly from a set of non-determined steps and its shapes are taken from nature such as tree fractal antenna. Deterministic fractal has been produced as a result of an iterative common types of fractal MSA such as Koch, Sierpinski, Hillbert, Minkowski and Cantor. There are two substantial properties of fractal MSA that are space filling and self-similarity properties [6, 7]. Space filling can be used for size reduction and enlarge the operative current length of MSA by the iteration number intensification under the same area, while self-similarity can be exploited for designing dual or multiple band microstrip antennas. On the other hand, fractal geometries can be used to design a variety of wideband and ultra-wideband microstrip antennas as reported in [8-13] using different methodologies.

In [8], symmetrical slot geometries were employed to design broadband microstrip antenna. Its performance had been realized by merging diverse downscaled varieties of a configuration of "island-like" space-filling slot antennas without changing the total antenna size. Correspondingly, symmetric slots have been used to enhance the axial bandwidth for microstrip fractal antennas reported in[9] to acquire circular polarization performance. In [10], a miniature wideband fractal MSA for wireless applications was proposed using circle inscribed octagon and Coplanar Waveguide (CPW) feed. It uses FR4 substrate with dimensions of (60 x 60) mm$^2$. This proposed design has been investigated up to three iterations. Full ground plane is used with thickness of 1 mm. Simulation results indicate that this antenna has a various resonance frequencies with various frequency ranges. This antenna is relevant for satellite communications and radio communications. In [11], a pentagon fractal antenna for above 6 GHz band applications was designed using coaxial feed. This antenna is appropriate for applications in fixed wireless systems. Koch fractal based hexagonal patch antenna for circular polarization has been designed for ultra-wideband application as explained by [12] using microstrip inset feed and a combination of two fractal geometries of Koch and Sierpinski. Partial rectangular shape ground plane has been employed to acquire wider bandwidth. This MSA is appropriate for C and X frequency band applications under IEEE and Multimedia standards. An embedded

configuration of a miniature wideband circular polarization microstrip fractal antenna is introduced in [13] for wideband applications. The suggested design has a Spidron fractal slot with a supplementary rectangular slit and an embedded

Spidron fractal patch. A microstrip tapered feedline is organized for the excitation and alleviating of hybrid coupler.

This study presents the design of highly compact fractal MSA for wideband applications and investigates the advantages of circular patch with a slot of pentagon shape up to three iteration levels. To reach an optimum bandwidth, two techniques are used as in fractal geometry technique and partial ground plane with rectangular shape. The design of optimal iteration design has been successfully simulated and fabricated with very electrical specifications. The measured results agree well with the simulations.

## 2. Design Concept

The conventional construction of MSA is shown in Figure1. It mainly consists of top, substrate and bottom layers. The top layer mainly comprises two parts; the first one is called patch that may take any possible geometric shape and the second one is called microstrip feed line. This layer is photo engraved on substrate [14]. The most common used type of substrate layer is FR4 since it is widely available in the market and has low value of loss tangent. The performance of antenna can be improved by controlling the thickness of substrate *h*, so that it is considered as principal factor for determining antenna performance. Using thicker substrate with low permittivity value $\in_r$ makes antenna parameters improved, but at the same time it has a drawback of increased antenna size. Therefore, a tradeoff should be made between antenna performance and antenna dimensions [15]. The last layer of MSA is called bottom or ground plane layer. It may take any form and it can be utilized as full or partial ground plane. It plays a vital role to enhance the bandwidth of MSA.

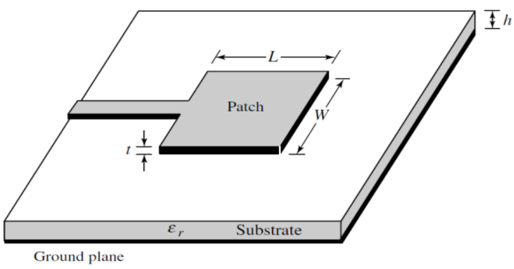



Figure 1 Components of MSA

The proposed model is designed based on iterative method using only three iterations. Higher iteration numbers make the antenna parameters not modified straightforwardly and increase the complexity of fabrication process as the iteration number increases. The design concept is based on "Trial and Error" principle for reaching to desired resonant frequency according to dimensions scaling of proposed antenna structure as similar as antenna design principles reported in [1, 5, and 14]. FR4 substrate has been used in antenna design with $\in_r$ =4.3 and *h*=1.5mm. Initially, patch circular base radius $R_1$ has been chosen based on desired fundamental resonance, which can be calculated based on [14] by:

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

Where *h* is thickness of substrate, $\in_r$ is a permittivity, *f* is a fundamental resonance frequency.

The determined radius $R_1$ of proposed model is equal to 7.5mm which represents the base circular patch or zero iteration as shown in Figure 2 (a).

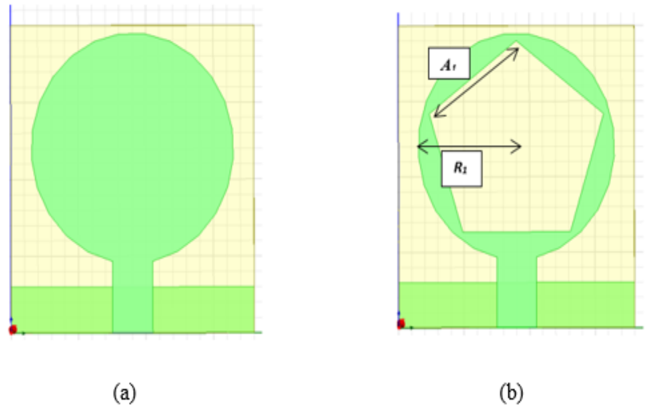



Figure 2 (a) Zeroth Iteration and (b) First Iteration

Based on [16], the side length of pentagon slot $A_k$ can be found by :

$$A_k = R_K * \sqrt{\frac{5-\sqrt{5}}{2}} \quad \text{……………………….. (2)}$$

Where $k$ = 1, 2, 3 (iteration index) and $R_k$ represents the radius of three circles, $R_1$, $R_2$ and $R_3$. The second step is etching a regular pentagon slot with estimated side length A1( by Trial and Error ) of 8.22mm in order to obtain the first iteration that is shown in Figure 2 (b) based on converging to fundamental resonance. The side length of the second and third pentagon is equal to 6.1 and 4.11mm accordingly. Correspondingly, the area of pentagon $P_k$ can be found by [16]:

$$P_k = 1.7204 * A_k^2 \quad \text{…………………………… (3)}$$

The area of first, second and third regular pentagon slots $P_1$, $P_2$ and $P_3$ are 116mm$^2$, 65mm$^2$ and 29mm$^2$ respectively. For second iteration, a second circle with a radius of $R_2$ is etched inside pentagon slot frame. The radius of second circle $R_2$ can be calculated by :

$$R_j = \frac{R_i}{S} \quad \text{…………………………………… (4)}$$

Where i =1, 2, $j$= 2, 3 and $S$ is an estimated scale factor that used in this design as constant value equal to 1.3 (estimated by Trial and Error ) based on converging to fundamental resonance. Also, a second regular pentagon slot is etched inside second circle with side length of 6.17mm in order to attain the second iteration. Finally, the same procedure will be repeated to obtain the third iteration by etching a regular pentagon slot with side length of 4.11mm inside third circle (inner circle) with radius of $R_3$ equal to 4.58mm that calculated by equation (4). The second iteration, third iteration and bottom views are shown in Figure 3.

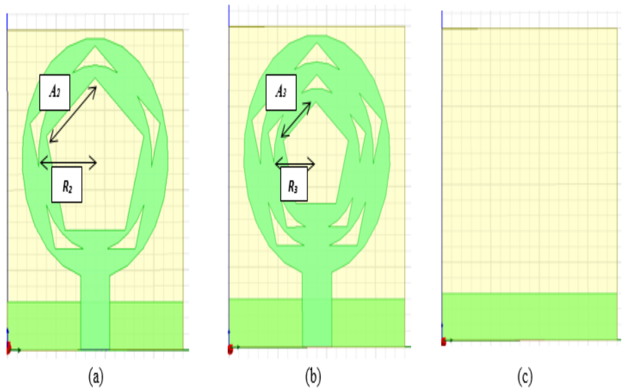



Figure 3 (a) Second iteration, (b) Third iteration(c) Bottom view

The FR4 substrate as rectangular shape of 20 mm length and 18mm width has been used. The partial ground plane has a rectangular shape covering the feed line with a gap *g* equal to 1.5mm away from circular patch. Also, microstrip line feed is the type of feeding used in this design since it is simplest type and easy to manufacture. After optimization process, the parameters of proposed antenna are listed in Table 1. As well, the final geometrical view of proposed fractal MSA is illustrated in Figure 4**.**

Table 1: The parameters of proposed model.

| Parameter | value | parameter | Value |
|---|---|---|---|
| Permittivity $E_r$ | 4.3 | Radius of first circle $R_1$ | 7.5mm |
| Thickness of substrate *h* | 1.5mm | Radius of second circle $R_2$ | 5.77mm |
| Width of substrate $W_s$ | 18mm | Radius of third circle $R_3$ | 4.58mm |
| Length of substrate $L_s$ | 20mm | Internal radius of pentagon1 $r_1$ | 5.96mm |
| Width of ground $W_g$ | 18mm | Internal radius of pentagon2 $r_2$ | 4.55mm |
| Length of ground $L_g$ | 3mm | Internal radius of pentagon3 $r_3$ | 2.95mm |
| Width of feed line $W_f$ | 3mm | Gap between ground and patch *g* | 1.5mm |
| Length of feed line $L_f$ | 4.65mm | Side of inner pentagon $A_3$ | 4.11mm |

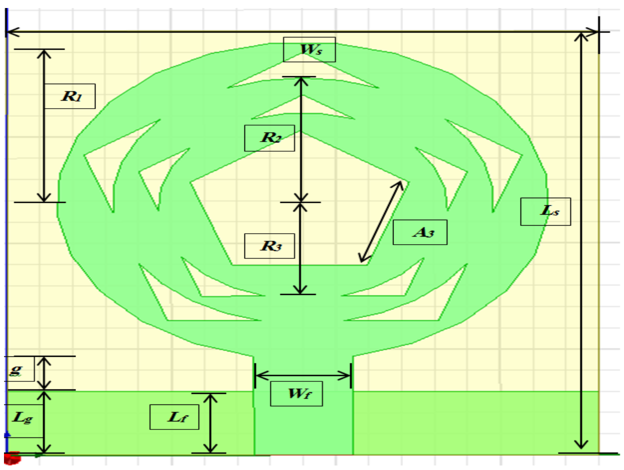



Figure 4 Geometrical view of projected fractal MSA

## 3. Simulation results and discussion

The proposed model has been designed and simulated by using Finite Element Method (FEM) based on HFSS version 2014. A comparison between different iterations is listed in Table 2.

Table 2: Comparison of proposed model based on various iteration numbers.

| Iteration `no. | S1.1 (dB) | Resonance frequency (GHz) | Impedance bandwidth | Radiation efficiency | Gain (dB) |
|---|---|---|---|---|---|
| 1st | -38.3 | 4.5 | 17.7% | 89.13 % | 3.48 |
| 2nd | -40.5 | 5.2 | 64.7% | 95.4 % | 3.48 |
| 3rd (Proposed) | -33,-41 | 5.7, 7.9 | 70% | 97 % | 3.10 |

It is obvious that at third iteration, the best return loss S1.1 values are equal to -33 and -41 dB at two resonance frequencies of 5.7 and 7.9 GHz with the widest bandwidth among other iterations. Also, a comparison of return loss S1.1 at various frequencies for various iteration numbers is shown in Figure 5.

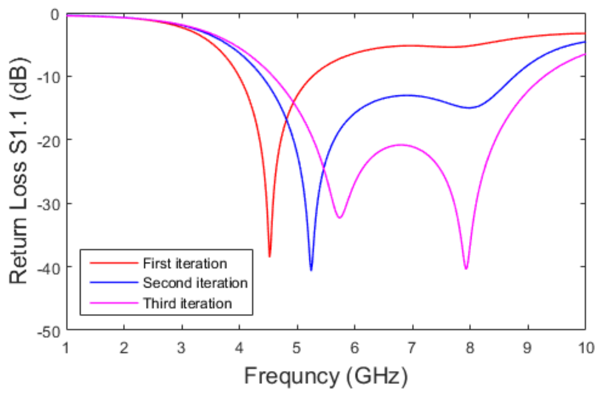



Figure 5 Simulated Return Loss S1.1 for Various Iterations No.

The parametric investigations of ground plane length $L_g$ is used to show the effect of $L_g$ variation on the performance of proposed model. At first, the length of feed is adjusted to 2 mm and increased by 0.5mm up to 4mm. It is obvious that excellent impedance matching can be obtained when $L_g$ equals to 3mm. The results are summarized in Table 3. A comparison of return loss at various frequencies for different values of $L_g$ is shown in Figure 6.

Table 3: Comparison of proposed model based on $L_g$.

| Length of ground (*Lg*) | S1.1(dB) | Resonance frequency (GHz) | Impedance bandwidth | Radiation efficiency | Gain (dB) |
|---|---|---|---|---|---|
| 2 mm | (-23.4,-17.6) | (5.2, 7.6) | 64.41% | 96.9% | 3.02 |
| 2.5 mm | (-26, -21) | (5.4, 7.7) | 66.17% | 97% | 3.04 |
| 3 mm (Proposed) | (-33,-41) | (5.7, 7.9 | 70% | 97 % | 3.10 |
| 3.5 mm | (-27.5,-27.8) | (5.9, 8.1) | 69.1% | 97.4% | 3.29 |
| 4 mm | (-19,-20.3) | (6, 8.7) | 73.5% | 97% | 4.37 |

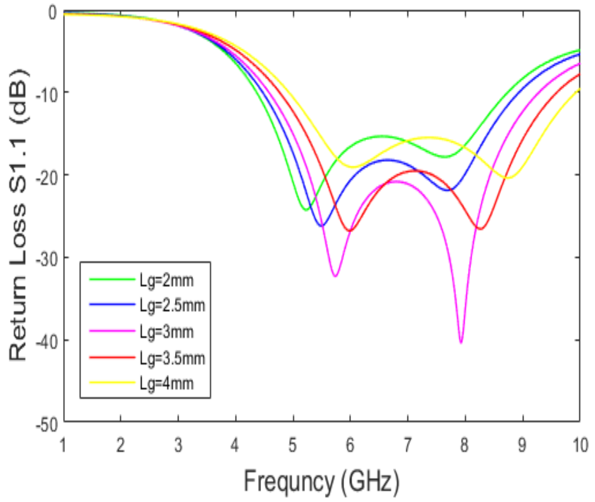



Figure 6 Simulated Return Loss S1.1 for Various Values of length of ground $L_g$

The width of feed line $W_f$ is changed tentatively to acquire wide bandwidth and show the effect of $W_f$ variation on the performance of proposed model. At first, the width of feed is taken 2 mm and increased by 0.5mm until 4 mm. It is clear that when $W_f$ equal to 3mm, the optimal return loss S1.1 can be observed as depicted in Table 4 . The comparison of return loss at a number of frequencies for different values of $W_f$ is presented in Figure 7.

Table 4: Comparison of proposed model based on $W_f$.

| Width of feed $W_f$ | S1.1(dB) | Resonance frequency (GHz) | Impedance bandwidth | Radiation efficiency | Gain (dB) |
|---|---|---|---|---|---|
| 2 mm | -15 | 7 | 55.88% | 97.08% | 3.14 |
| 2.5 mm | -28 | 7.2 | 66.17% | 97.40% | 3.13 |
| 3 mm (Proposed) | (-33, -41) | (5.7, 7.9) | 70% | 97.05 % | 3.10 |
| 3.5 mm | (-23, -23) | (5.6, 8.5) | 69.11% | 97.19% | 3.18 |
| 4 mm | (-18, -19) | (5.5, 8.6) | 66.17% | 96.81% | 3.25 |

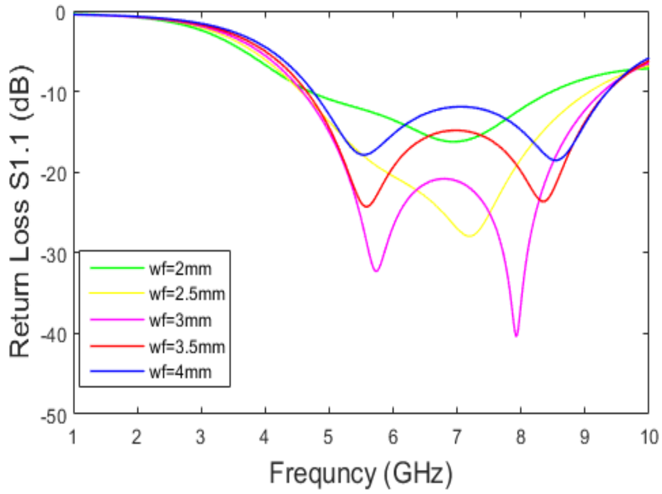



Figure 7 Simulated Return Loss S1.1 for Various Values of width of ground $W_f$

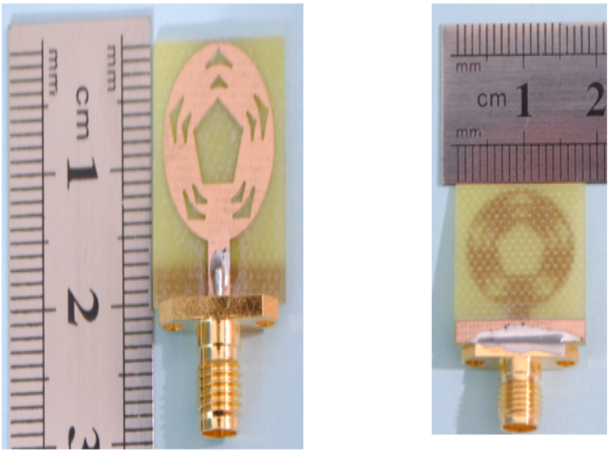
As depicted in the Table 5, a comparison of our work with other testified microstrip antennas in the literature has been made. The proposed antenna in this study is mostly more compact than microstrip antennas in [12, 17-20] in the related applications.

Table 5: Size comparison of proposed antenna with references [12, 17-20]

| Reference | Size($mm^2$) | Resonant Frequency (GHz) |
|---|---|---|
| [12] | 30 x 35 | 3.1/ 6.9/ 8.4/ 9.1 |
| [17] | 173 x 70 | 3.1/5/7/10.6 |
| [18] | 17.2 x 20 | 5.25/ 5.8 |
| [19] | 80 x 80 | 4.4/5.5/6.2 |
| [20] | 100 x 100 | 3.1 to 10.6 |
| Proposed | 20 x 18 | 5.7/7.9 |

## 4. Measurement

After locating the finest values for fractal MSA design based on in Tables 1-4, the proposed antenna is fabricated on a substrate of FR4 with dimensions of (20x18) $mm^2$. It has been measured using Agilent 8510C network analyzer. The fabricated antenna is shown in Figure 8. The simulated and measured return loss S1.1 results are shown in Figure 9.



(a) (b)

Figure 8 Fabricated Prototype of Proposed Antenna (a) Top View (b) Bottom View

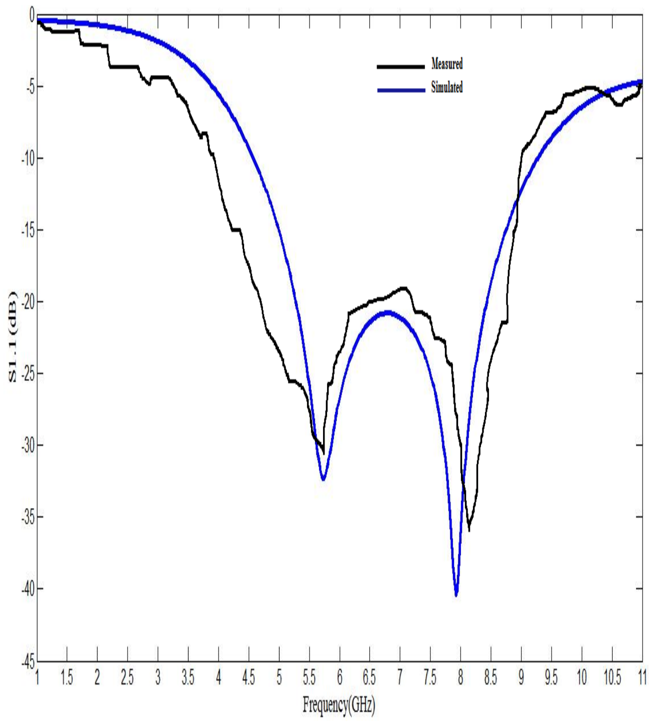
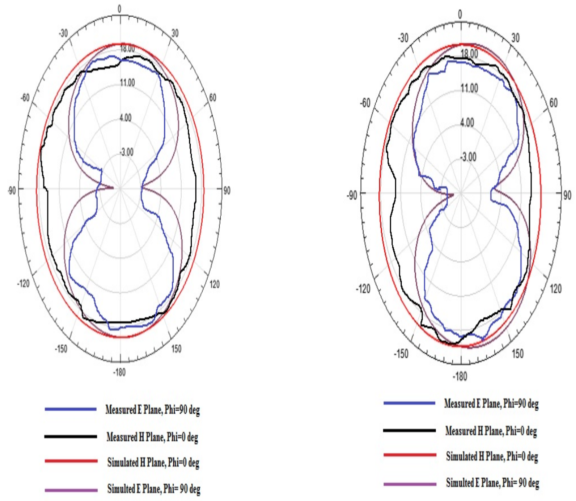



Figure 9 Simulated Return Loss as Compared with Measured Return Loss

The S1.1 responses point out an adequate agreement between simulated and measured results with slight deviations. The differences between them are attributable to SMA connector mismatches, conductor losses and fabrication tolerance.

The simulated and measured 2D Radiation patterns of proposed antenna for two resonance frequencies are shown in Figure 10. It stands for the far field radiation pattern at 5.7 and 7.9 GHz respectively. It is clear that proposed antenna has a bi- directional radiation patterns. Useful part of radiation pattern will be raising plane for two values of phi; 0 degree for H-plane and 90 degree for E-plane. The simulations and measurements of radiation patterns are in good conformity.




a)5.7GHz (b) 7.9GH

Figure 10 Simulated and measured E field radiation patterens at (a)5.7GHz and (b)7.9 GHz

The simulated and measured values of gain versus frequency are shown in Figure 11 over 5-11 GHz frequency range. The gain starts gradually to increase from 5 GHz until reaches the peak value of (4.3dB in the simulation and 4.1 dB in the measurement) at 9GHz. Then, it gradually decreases until 11 GHz. Both simulated and measured gain results are in fine agreement.

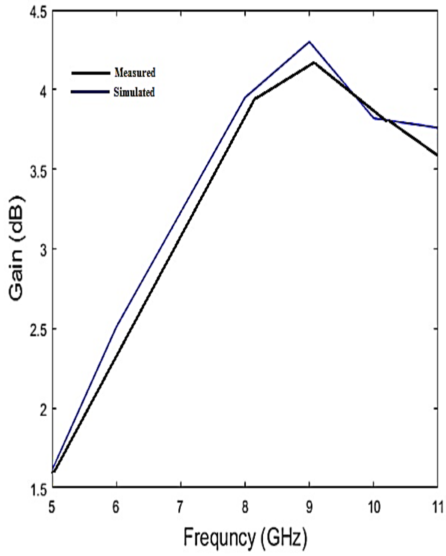



Figure 11 Simulated and measured gains versus frequency

## 5. Conclusions

A new compact fractal MSA using pentagon slot inside circular patch resonator is proposed to operate at a range of frequencies of (4.5-9.3) GHz. It has been simulated by HFSS software to obtain the best geomatric design and successfully verified by fabrication and measurement. The iterative method is used in this design up to third iteration. The length of ground plane $L_g$ and the width of feed line $W_f$ are optimized and it is found that 3mm width of feed and 3mm length of ground are the best values to get the widest bandwidth. The simulated return loss values are -33 and -41 dB at resonant frequencies of 5.7 and 7.9 GHz with gain of 3.2 dB and impedance bandwidth of 4.8 GHz . There are adequte agreement between simulated and measured results in terms of input reflection, far field radiaton patterns and gain. The proposed fractal MSA has highly compact FR4 substrate size of (20 x 18) $mm^2$ that is appropriate for wideband applications as in weather radar, satellite communication and C band systems.

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