A Compact Super Wideband Monopole Antenna Design using Fractal Geometries

Babu Lal Shahu[1], Srikanta Pal[2], Neela Chattoraj[3]

Abstract - **A compact monopole antenna using fractal geometries is proposed for super wideband (SWB) application. The proposed antenna has a compact size of 22 x 33.4 mm^2 and is designed using MOM based Full Wave Electromagnetic Simulator IE3D. Parametric studies have been performed to show the effect of various antenna parameters. The proposed antenna is able to achieve super wide bandwidth ranging from 3 GHz to 26 GHz with measured peak gain variation from 1.9 to 7 dBi and very good radiation pattern. The proposed antenna is fabricated and measured to demonstrate the performance characteristics. Simplicity, compactness and stable radiation pattern made the antenna useful for UWB and higher frequencies applications.**

Keywords – **Monopole antenna, Fractal geometries, Super wideband (SWB), Microstrip line feed**

I. INTRODUCTION

Modern telecommunication system requires antenna with compact size and higher bandwidth to cover both short and long range transmission. Although simple planar monopole antennas are able to cover entire UWB range from 3-11 GHz, they are suitable only for short range communication. Nowadays there is great demand of SWB antennas which can be used for both short and long range transmission. The term SWB is generally used to indicate the bandwidth, which is greater than a decade bandwidth. The present requirement of SWB antenna is to provide at least the ratio bandwidth of 10:1 at 10-dB return loss [1]. SWB technology is now becoming an essential part of modern wireless communication due to its ability of extremely large bandwidth and high data rate and found application in military and civilian systems. Designing a low profile and compact size antenna with good characteristics is a challenging task for researcher nowadays. Fractal is very good solution to achieve a compact, low profile antenna with multi-band and broadband characteristics due to its two most common properties: self similarity and space filling [2]. The discontinuities due to convoluted and jagged shape of fractal increases bandwidth and effective radiation of antenna. The self similarity property of fractal causes multiband and broadband behavior and space filling property leads to size reduction [3 - 4]. In open literature, few papers have been published using different geometries [6-14] on SWB antenna. For examples, a super wideband fractal antenna presented in [3] by applying the fractal generator to a normal wire square loop of size 35 mm x 35 mm. Designing of super wideband circular-hexagonal fractal antenna is reported in [4] with the compact size of 31 mm x 45 mm. A monopole antenna for SWB application is presented in [5] by embedding a semi-elliptical complementary slot into asymmetrical ground plane. However the structure of this antenna is complicated and has the size of 77 mm x 35 mm. A compact semi-elliptical patch antenna fed by a tapered coplanar waveguide (CPW) is presented in [6] for bandwidth ratio of 19.7:1. A novel half-circular antipodal printed slot antenna with super-wideband performance is presented in [7] for polarization diversity application. A circular shaped monopole antenna for SWB application of ratio bandwidth of 21.9:1 is reported in [8]. Designing of compact monopole UWB antenna using Giusepe Peano and Sierpinski carpet fractal is presented in [9], but its wide band frequency response is limited up to 15 GHz.

In this paper, a compact SWB antenna with an electrical dimension of 0.35λ x 0.23λ x 0.016λ (where λ corresponds to lower edge frequency of operating band) using the combination of fractal geometries is presented. The patch of the proposed antenna is a rectangle with first iteration of Giusepe Peano fractal on its boundary. Inside the surface of rectangular patch, Sierpinski Koch snowflake slots of first iteration of different size is applied. The combination of a semi-circle and rectangle is used to design the ground of proposed antenna to achieve the desired impedance bandwidth.

II. DESIGN OF PROPOSED ANTENNA

The recursive process for obtaining Giusepe Peano fractal of 1st iteration, which is applied at the edges of rectangular patch, is shown in Fig. 1. Fig. 2 is made simply by etching a fractal Koch snowflake shaped slot at the center and four other similar slots of different sizes at the corner of rectangular patch. The radii of circumferences that circumscribe the center slot and corner slots are 3 mm and 1.5 mm respectively. Although the increase in number of iteration leads to antenna miniaturization, the design of antenna becomes too complicated and fabrication also becomes too difficult. The geometry of proposed antenna after applying the above two geometries is shown in Fig. 3. The structure of proposed fractal antenna with geometrical parameters is shown in Fig. 4. The proposed antenna is fed using microstrip line with tapering at upper section of feed line. The width of

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feed line s at the bottom is 4.8 mm corresponding to 50 Ω characteristic impedance. The upper section of feed line is tapered to improve the impedance bandwidth where its width is 2.4 mm.

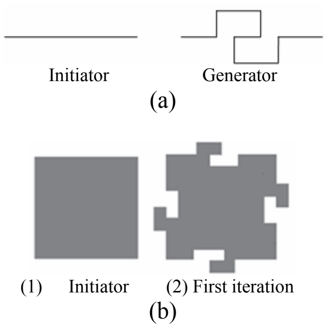

Fig. 1. Giusepe Peano fractal (a) Initiator and generator (b) Shape of fractal applied at the edges of metallic patch

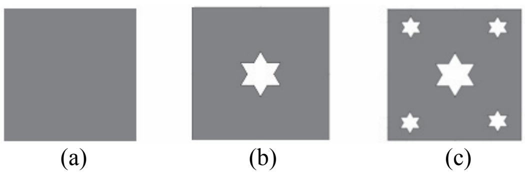

Fig. 2. Square patch with Koch slots

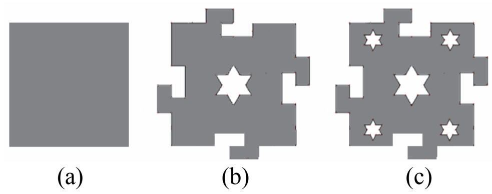

Fig. 3. Design procedure for proposed fractal geometry

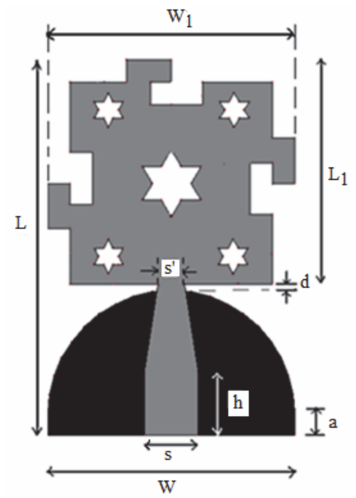

Fig. 4. Structure of proposed antenna

The length of feed line is given as $L - L_1$, where L is total length of proposed antenna including ground plane and L_1 is the length of patch. The ground plane is combination of a semi-circle of radius 11 mm and a rectangle of size 22 mm x 2 mm. The length of ground plane depends on the height of rectangle and radius of semicircle and given as $(a+R)$, where a is height of rectangle and R is radius of semicircle of the ground plane. Also $L - L_1 = a + R + d$, where d is gap between patch and ground plane. Now the length of tapered section of feed line can be given as $(a+R+d-h)$, where h is the height of rectangular section of feed line.

If the length of initiator is X, the length enclosed by any Peano pre-fractal curve for nth iteration structure, X_n is [15]:

$$X_n = 2^n X_{n-1}, \quad \text{for } n \geq 1. \tag{1}$$

The free space wavelength (λ) corresponds to lower edge frequency and guide wavelength λ_g are related as:

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}}. \tag{2}$$

Where ε_{eff} is effective dielectric constant and is given as

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}. \tag{3}$$

The proposed antenna is designed and optimized using IE3D simulator on RT/Duroid 5880 substrate with relative permittivity of 2.2, thickness 1.57 mm and loss tangent 0.0009. The rectangular patch has the dimension of 22 mm x 20 mm. The proposed antenna has overall size of 33.4 mm x 22 mm (L x W). The optimized geometrical parameters of proposed antenna are shown in Table 1.

TABLE 1
GEOMETRICAL DIMENSION OF PROPOSED ANTENNA PARAMETERS

Parameters	Dimension (mm)	Parameters	Dimension (mm)
L	33.4	h	5.8
W	22	s	4.8
L_1	20	s'	2.4
W_1	22	a	2
d	0.5		

Following factors help to improve performance of proposed antenna:

1) The Koch fractal shape slot helps to improve the current distribution to the exterior of antenna.
2) Tapering of feed line helps to improve the impedance bandwidth as shown in Fig. 5.
3) The combination of rectangular and semi circular ground improves the impedance bandwidth a lot as shown in Fig. 6.

Comparison of proposed antenna performance with few other SWB antennas is presented in Table 2.

TABLE 2
PERFORMANCE COMPARISON OF PROPOSED ANTENNA WITH OTHER SWB ANTENNAS

Ref.	Size (mm^2)	Bandwidth (GHz) $\|S_{11}\| < -10$Db	Gain Variation (dBi)	Complexity
Proposed	22 x 33.4	3.1 – 26	1.9 – 7	Low
[2]	60 x 60	10- 50	0 – 9	High
[4]	31 x 45	2.18- 44.5	0 – 7	Very high
[5]	35 x 77	1.44- 18.8	0.9 – 6.9	Very high

III. Simulation Results and Parametric Study

The final configuration of the proposed antenna is obtained after optimizing the dimensions of the various controlling parameters of the fractal constituents, feed line and ground plane. Effect of different parameters/factors on performance of antenna in terms of return loss is discussed below:

A. *Effect of Shape of Feed Line*

A comparative result with two different shapes of feed line is shown in Fig. 5. Result shows that the performance of tapered feed line is much better as compared to straight feed line. Impedance bandwidth for tapered feed line is much greater as compared to straight feed line.

B. *Effect of Shape of Ground Plane*

A comparative result for rectangular shaped ground plane, semi-circular ground plane and combination of rectangle and semi-circular shaped ground plane is depicted in Fig. 6. The performance of proposed antenna with rectangular ground plane is unable to obtain the required impedance bandwidth. Also without rectangular section i.e. only with semi-circular ground, result is useless. The impedance bandwidth with combination of rectangular and semi-circular ground plane is 3 GHz to 26 GHz for 10dB return loss.

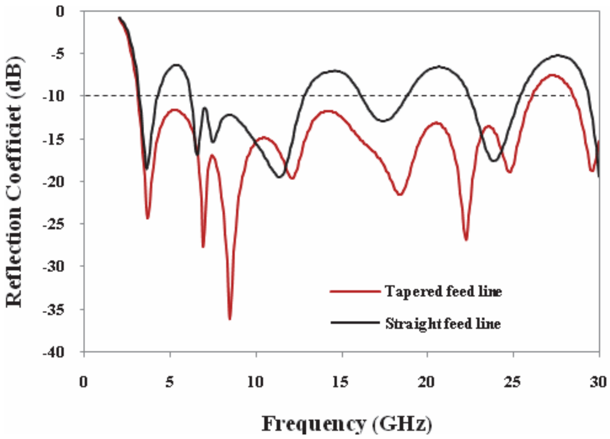

Fig. 5. Simulated results with different shapes of feed line

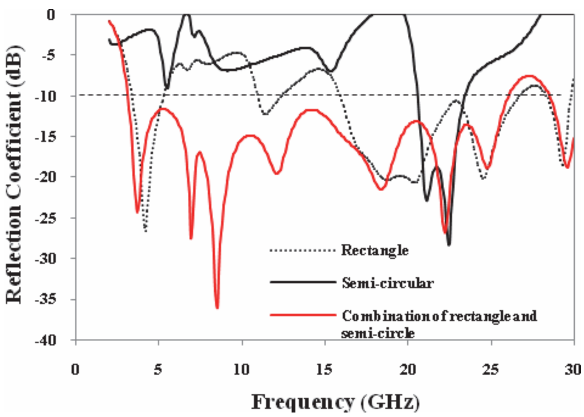

Fig. 6. Simulated results with different shapes of ground plane

C. *Effect of Geometrical Modification*

Comparisons of antenna performance for different stages of modifications are depicted in Fig. 7. Very little discrepancy is observed. For all modification proposed antenna maintain almost same impedance bandwidth. However design complexity is increased for higher iteration.

D. *Effect of Parametrical Dimensions*

Variation of reflection coefficient in dB with height of rectangular section of feed line h is shown in Fig. 8. Impedance bandwidth (10 dB) is decreased for very large or very small value of h. The optimized value of h is taken as 5.8 mm. Performance comparison with gap between patch and ground plane d is depicted in Fig. 9. Impedance bandwidth is decreased for small value of d. The optimized value of d is chosen as 0.5 mm. Performance of antenna with variation in height a of rectangular section of ground plane is shown in Fig. 10. Impedance bandwidth is decreased with increase of a but also the lower end of frequency is shifted towards the lower side which is useful.

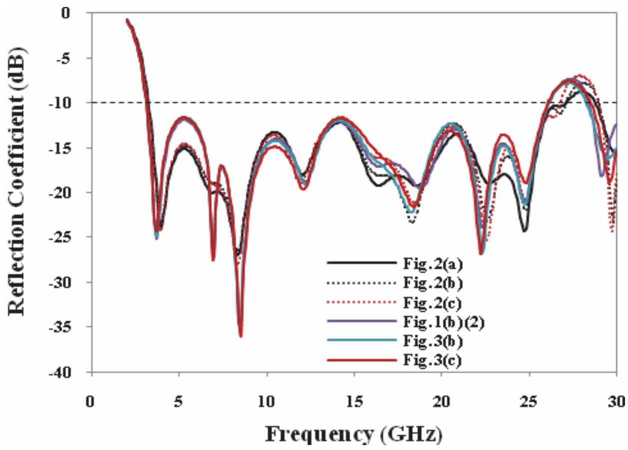

Fig. 7. Simulated results with different modification of proposed geometry

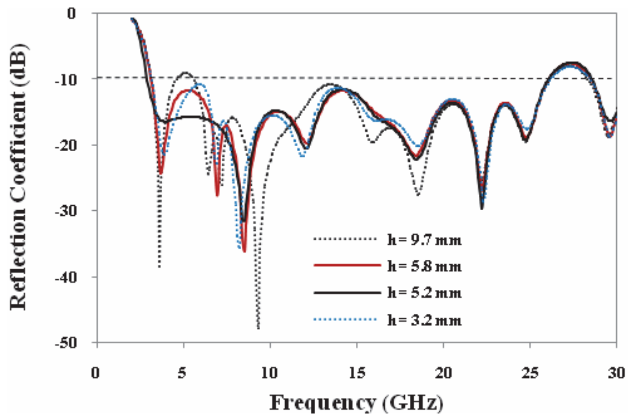

Fig. 8. Simulated results with different height of rectangular section of feed line

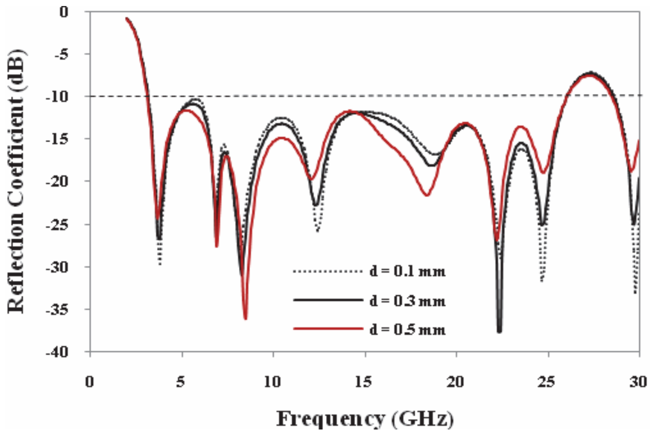

Fig. 9. Simulated results with variation in gap between patch and ground plane

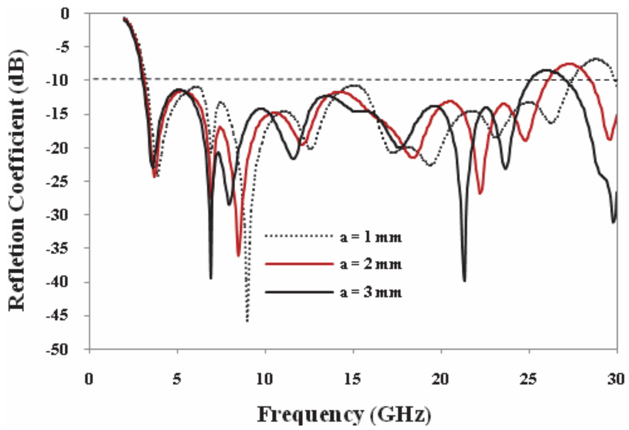

Fig. 10. Simulated results with variation in height of rectangular section of ground plane

III. Results and Discussion

To evaluate the performances of optimized antenna, the prototype of proposed antenna is implemented and fabricated. The photograph of fabricated prototype is shown in Fig. 11. Measured return loss is plotted to indicate that it covers the wide bandwidth from 3.1 GHz to 25.5 GHz for $|S_{11}| < 10$ dB. The comparison of simulated and measured return loss characteristics shown in Fig. 12 shows a very good agreement. The little discrepancy may be due to error in fabrication and bad soldering effect. Also, the simulation results were taken using microstrip line feed, whereas practically SMA connector was used. The improper transition between SMA connector and microstrip line may lead to losses and shift in frequency. The variation in dielectric constant, height and loss tangent of the actual substrate and that of the assumed one for the simulation may cause in shift in the frequency. As measurement is taken in uncontrolled environment which also leads discrepancy between simulated and measured result. The disagreement between measured and simulated result is great in high frequencies as parasitic coupling present between the top patch layer and the ground plane at various parts of the antenna which actually acts as low pass filtering circuit. This will cause limited wide frequency band behavior of the antenna profile.

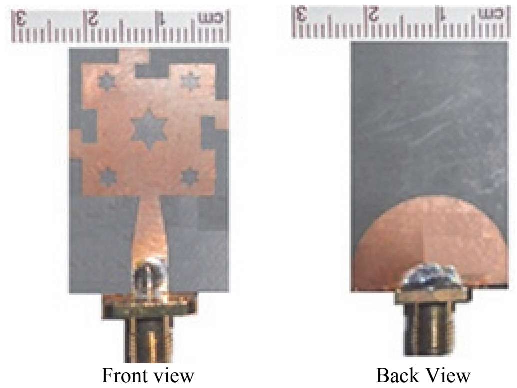

Fig. 11. Photograph of fabricated antenna

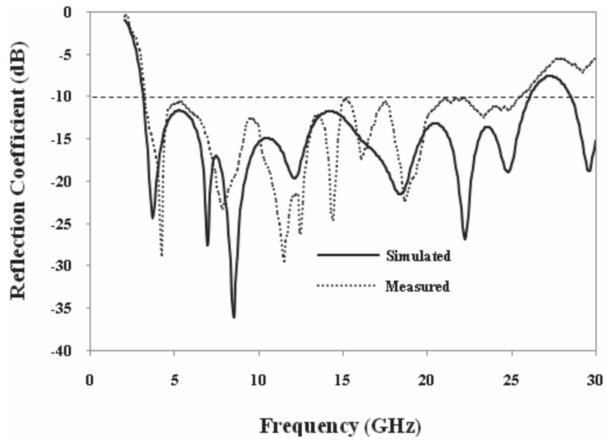

Fig. 12. Simulated and measured return loss

The comparison of measured antenna gain with simulated one from 2 GHz to 30 GHz is shown in Fig. 13. Result shows reasonable agreement throughout the desired frequency range. The measured peak gain varied from 1.9 to 7 dBi in the 3.1 GHz to 25.5 GHz frequency range. Measured E-plane and H-plane radiation patterns at 3.1 GHz, 10 GHz, 18 GHz and 24 GHz are depicted in Fig. 14. Nearly stable and figure of eight patterns are observed in E-plane. The nature of radiation patterns in H-plane is nearly omnidirectional.

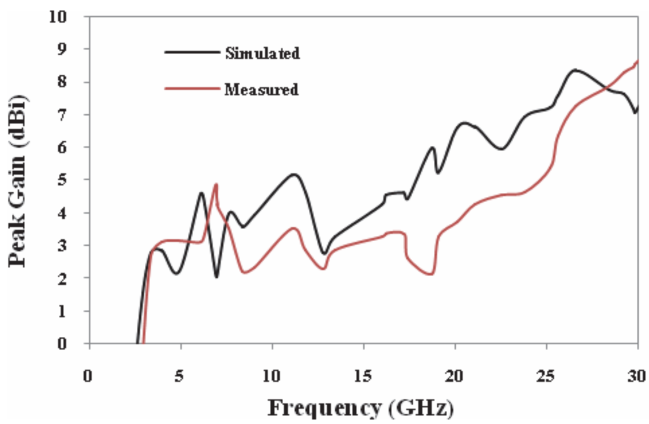

Fig. 13. Simulated and measured gain

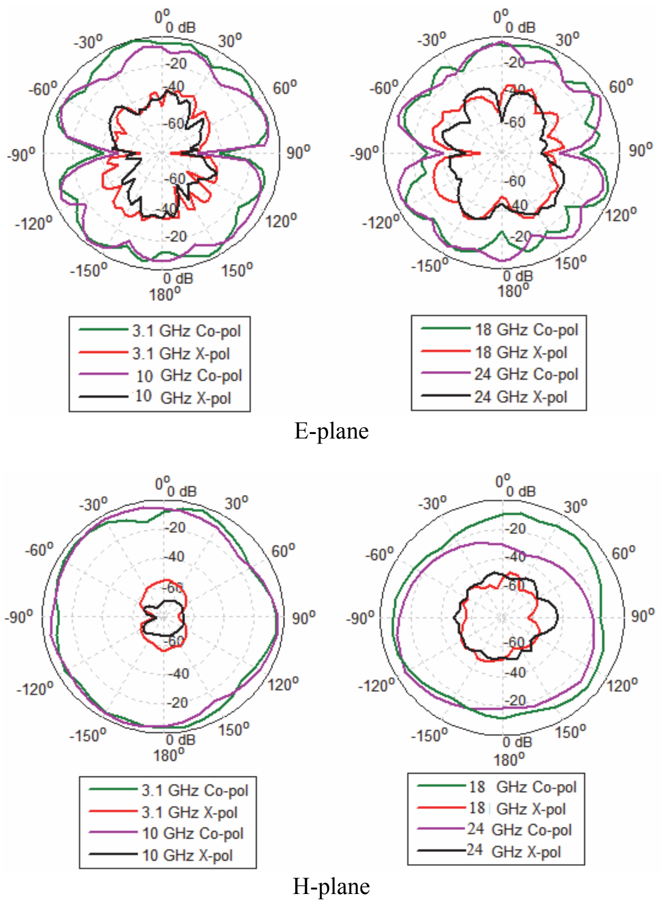

Fig. 14. Measured radiation patterns

IV. CONCLUSION

In this paper, compact monopole antenna using fractal geometries is presented. The proposed antenna is fed using microstrip line and designed on RT/Duroid 5880 substrate of $\varepsilon_r = 2.2$ and height 1.57 mm. It has compact size of 33.4 x 22 mm^2 .The measured impedance bandwidth ($S_{11} < -10\,\text{dB}$) of proposed antenna is 22.4 GHz, from 3.1 to 25.5 GHz. The maximum of measured peak gain is 7 dBi. Also the proposed antenna is able to achieve stable and omnidirectional radiation patterns. The antenna is very simple, compact and can be used for UWB and higher frequencies applications.

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