International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:9, No:7, 2015

On the Design of Wearable Fractal Antenna

Amar Partap Singh Pharwaha, Shweta Rani

***Abstract*—**This paper is aimed at proposing a rhombus shaped wearable fractal antenna for wireless communication systems. The geometrical descriptors of the antenna have been obtained using bacterial foraging optimization (BFO) for wide band operation. The method of moment based IE3D software has been used to simulate the antenna and observed that miniaturization of 13.08% has been achieved without degrading the resonating properties of the proposed antenna. An analysis with different substrates has also been done in order to evaluate the effectiveness of electrical permittivity on the presented structure. The proposed antenna has low profile, light weight and has successfully demonstrated wideband and multiband characteristics for wearable electronic applications.

***Keywords*—**BFO, bandwidth, electrical permittivity, fractals, wearable antenna.

I. Introduction

RECENTLY wearable antennas have gained a lot of attention and become one of the interesting research areas in antenna applications, since they can be integrated directly in the clothing and lead to a light weight cheap device [1], [2]. In wearable applications, bands of interest include the ISM (Industrial Scientific and Medical) bands at 900 MHz, 2.4 GHz, 5.15 GHz, 5.2 GHz, 5.8 GHz and the MICS (Medical Implant Communication Services) band at 400-405 MHz [3].

The growth of the telecommunication systems is driving the engineering efforts to develop multi/wideband and compact systems [4]. This has initiated antenna research in many directions, one of which is by using fractal shaped antenna elements. The self-similar and space filling properties of the fractals has motivated antenna design engineers to adopt this geometry as a viable alternative to meet the requirement of miniaturization and multiband operation. The term fractal means broken or irregular fragments, was first defined by Mandelbrot [5] in 1975, to describe complex structures that possess an inherent self-similarity or self-affinity in their geometrical structures. There are several techniques published in literature to decrease the size of microstrip antenna such as shorting pins, introducing of U-slots, using of high permittivity substrates and fractal geometry [6]-[8]. Fractal geometry is a very good solution to this problem. The main advantages of fractal antenna over conventional antenna designs are its multiband operation and reduced size. Fractal antenna has useful applications in cellular telephone and microwave communications [9]. Since last few years, biologically inspired optimization techniques are becoming very popular in the field of antenna system engineering. Among them BFO has appeared as a strong contender and it is very helpful to solve various antenna applications because of its parallel architecture, probabilistic and deterministic nature [10]-[12]. As fourth generation wireless communication systems require more and more bandwidth, the requirement for wideband antennas increases as well [13]. This paper focus on the design and development of sierpinski carpet based fractal antenna whose dimensional parameters have been obtained using BFO. The presented design methodology provides a cost effective solution for various wireless and wearable electronic applications.

II. Antenna Design and Structure

The antenna design is rhombus in shape and inspired from the sierpinski carpet fractal structure. Every rhombus is a parallelogram with four equal straight sides whose opposite sides are parallel, opposite angles are equal and diagonals bisect each other. The successive iterations of the presented antenna geometry have been developed by implementing sierpinski carpet with 1/3 scaling factor on the base shape of the antenna.

In order to form the first iteration, original unit rhombus is scaled by 1/3 in both x and y direction to make first affine transformation then rhombus is cut in to nine congruent sub rhombuses in a 3-by-3 grid, and the centre rhombus is removed. The same procedure is then applied recursively to the remaining eight rhombuses to get the next iterations. Fig. 1 shows the base structure (zero iteration) and geometry of first three iterations of the proposed fractal antenna. An array antenna with rectangular patches has been described by C. A. balanis in [4]. The geometry of array antenna looks similar to sierpinski carpet antenna but at the place where sierpinski carpet has slots, the array antenna has microstrip patches and in places of patch in the carpet, the antenna array does not have any conducting layer. The antenna proposed in this paper is quite different from the antenna array described in [4]; firstly the places of slots in array antenna have been replaced with patches and second, the geometry of the patches is square whereas in the presented design the geometry of the structure is more like a rhombus parallelogram.

The antenna is designed on FR4 substrate of thickness, h = 1.57 mm with electrical permittivity, ϵr = 4.4.The patch size is characterized by the side of the rhombus ‘a’ and thickness ‘h’. Initially, the side of the designed antenna has been taken as a = 20 mm for the analysis of different iterations, later on the side of the proposed antenna has been optimized for wider bandwidth which is required for the operation of fourth generation wireless communication systems. The dimensions of ground plane are 20mm x 30mm. A probe feed is used to

Amar Partap Singh Pharwaha is with the Sant Longowal Institute of Engineering & Technology (Deemed University), Longowal, Sangrur, Punjab, India (corresponding author; e-mail: aps.aps67@gmail.com).

Shweta Rani is with the Bhai Gurdas Institute of Engineering & Technology, Sangrur, Punjab, India (e-mail: shwetaranee@gmail.com).

feed the antenna. As the dimensions of the patch are finite along sides of the rhombus shaped parallelogram, the fields at the edges of the patch undergo fringing. Generally the near field of microstrip patch antenna spread out in to the air region, around the substrate and also in to the dielectric surrounding the conductor pattern. This leakage in the field is commonly known as fringing effect. The amount of fringing is a function of the dimension of the patch, the height of the substrate and electrical permittivity of the substrate. Because of the fringing effects, the electrical size of the microstrip antenna looks greater than its physical dimensions. A good impedance matching can be calculated using (1) and (2) [4].

$$\varepsilon_{eff} = \frac{(\varepsilon r+1)}{2} + \frac{(\varepsilon r-1)}{2}\left[\frac{1}{\sqrt{1+12h/w}}\right] \quad (1)$$

$$Z_o = \frac{120\,\pi}{\sqrt{\varepsilon eff}\left[\frac{w}{h}+1.393+0.667\ln\left(\frac{w}{h}+1.444\right)\right]} \text{ for } \frac{w}{h} \geq 1 \quad (2)$$

A. Proposed IFS for Fractal Geometry

All Iterative Function system (IFS) represents an extremely versatile method for wide variety of useful fractal structures. IFS provide a general framework for the classification and manipulation of fractals [12]. The segments for self-affine fractal shapes are developed for each iteration of same dimensions and are derived using below given equation [6]. IFS transformation coefficients for the proposed fractal antenna are given in Table I.

$$w\,(x,y) = \begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} e \\ f \end{bmatrix} = Ax + t \quad (3)$$

TABLE I
IFS TRANSFORMATION COEFFICIENTS FOR THE PROPOSED FRACTAL ANTENNA

w	a	b	c	d	e	f
1	1/3	0	0	1/3	0	0
2	1/3	0	0	1/3	0	1/3
3	1/3	0	0	1/3	0	2/3
4	1/3	0	0	1/3	1/3	2/3
5	1/3	0	0	1/3	2/3	2/3
6	1/3	0	0	1/3	2/3	1/3
7	1/3	0	0	1/3	2/3	0
8	1/3	0	0	1/3	1/3	0

The generator is then obtained as [9]:

$$M1 = W1(A) \cup W2(A) \cup W3(A) \cup W4(A) \cup W5(A) \cup W6(A) \cup W7(A) \cup W8(A) \quad (4)$$

This procedure can be repeated for all higher iterations of the structure. The fractal dimension can be interpreted as a measure of the space filling properties and complexity of the fractal shape. The fractal similarity dimension is given by (5), where n is the total number of distinct copies and r is the scale factor of the consecutive iteration [6].

$$D = \frac{\log(n)}{\log(1/r)} = \frac{\log(8)}{\log(3)} = 1.892 \quad (5)$$

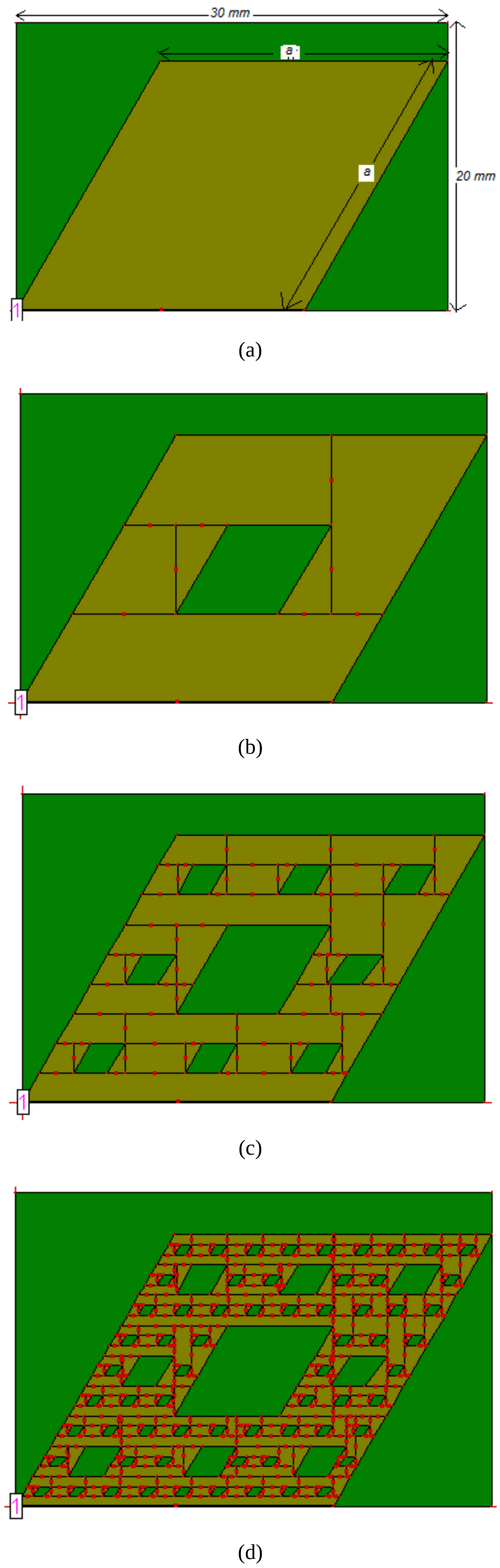


Fig. 1 Geometry of proposed antenna for (a) zero iteration (b) 1st iteration (c) 2nd iteration (d) 3rd iteration

B. BFO Implementation

The foraging optimization technique follows chemo taxis, swarming, tumbling, reproduction and elimination & dispersal. In chemo-taxis, the flagellum is configured as a left hand helix. The base of the flagellum rotates counter clockwise, produces force against the bacterium, which pushes the cell. Else, each flagellum behaves relatively independent of the others: rotate clockwise and bacterium tumbles [12]. During swarming, the bacteria move out from their respective places in the ring of cells by moving up with the width gradient to the desired value. During reproduction, the least healthy bacteria die and the others divide in to two, which are placed in the same location. This makes the population of bacteria to remain constant. The elimination and dispersal processes are based on population level long-distance motile behavior [10], [11]. The input parameters for BFO are the number of bacteria in the population *Nb*, the chemotactic loop limit *Nc*, reproduction loop limit *Nre*, the elimination–dispersal loop limit Ned and the probability of elimination–dispersal *Ped*.

The pseudo code of BFO algorithmic is as follows [12]:

Step1. Initialize input parameters.

Step2. Create a random initial swarm of bacteria θi (j, k, l), $\forall i$, i = 1 ... *Sb*.

Step3. Evaluate f (θi *(j, k, l)*), $\forall i$, i = 1 ... *S*.

Step4. Perform the chemotaxis for bacteria θi *(j, k, l)*.

Step5. Perform the reproduction process by eliminating half the worst bacteria and duplicating the other half

Step6. Perform the elimination-dispersal process for all bacteria θi *(j, k, l)*, $\forall i$, i =1 ...Nb, with probability $0<\leq Ped \leq 1$ where θi *(j, k, l)* represents the *ith* bacterium at the *jth* chemotactic, the *kth* reproductive, and the *lth* elimination and dispersal step.

III. Results and Discussion

A. Resonant Parameters of Proposed Fractal Structure

The simulation of the design is carried out by the method of moment based IE3D EM simulator. The simulated s-parameter results of the proposed antenna for zero, 1st, 2nd and 3rd iteration are shown in Fig. 2. Obtained results reveal that a size reduction of 13.08% of the base patch has been achieved for 3rd iteration without degrading the resonating characteristics of the presented antennas. From the presented results in Table II, it can be clearly visualized that except for zero iteration, which has one resonant frequency less than that of other higher iterations, with increase in iteration there is very less change in the s-parameters, such as return loss, resonant frequency, VSWR, input impedance and bandwidth of the antenna. A typical input characteristics *Zin = Rein + jImin* of the first three iterations for the proposed fractal antenna are shown in Fig. 3. In this paper only the first three iterations are considered since higher order iterations do not make significant effect on antenna properties. These results describe the multiband behavior of the proposed antenna and satisfy the self-similar property of fractals.

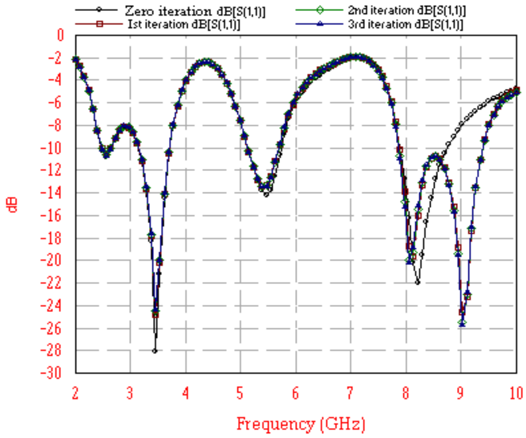
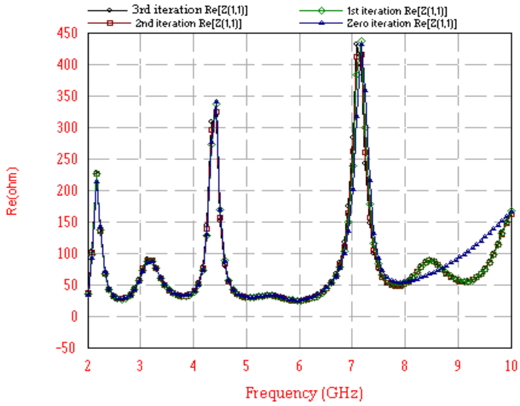
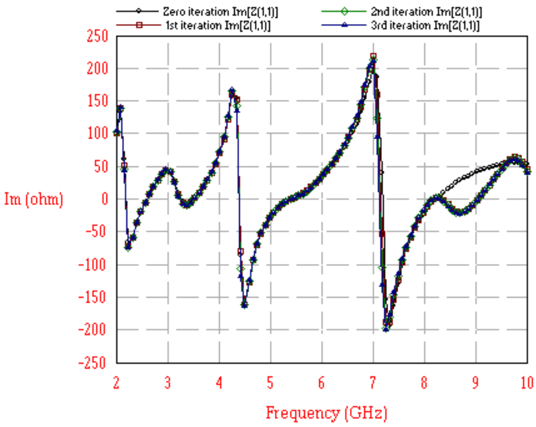


Fig. 2 Simulated S-parameters of proposed antenna for first four iterations



(a)



(b)

Fig. 3 Input Impedance of proposed antenna (a) Real part (b) Imaginary part

International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:9, No:7, 2015

TABLE II
RESONANT PERFORMANCE CHARACTERISTICS OF PROPOSED ANTENNA FOR ALL THE FOUR ITERATIONS

No. of Iterations	Resonant Frequency (GHz)	Return Loss (dB)	Input Impedance (Ohms)	VSWR
Zero Iteration	2.56	-10.88	-28.27-j5.57	1.80
	3.45	-28.15	-50.43-j3.90	1.08
	5.47	-14.24	33.87+j2.33	1.48
	8.22	-22.06	58.44-j1.40	1.17
1st Iteration	2.56	-10.65	27.72-j5.14	1.83
	3.45	-24.89	49.16-j5.59	1.12
	5.39	-13.47	32.50+0.18	1.53
	8.14	-19.73	60.84-j3.63	1.23
	9.03	24.64	55.83-j2.13	1.12
2nd Iteration	2.56	-10.66	27.71-j4.91	1.82
	3.45	-24.58	48.91-j5.74	1.12
	5.47	-13.42	32.57+j2.63	1.54
	8.06	-20.0	55.11-j9.23	1.22
	9.03	-25.53	55.3-j1.70	1.11
3rd Iteration	2.566	-10.77	27.91-j4.76	1.815
	3.455	-24.37	48.79-j5.86	1.129
	5.394	-13.47	32.51+j0.18	1.538
	8.061	-20.19	55.64-j8.70	1.217
	9.031	-25.74	55.20-j1.58	1.109

B. Analysis of Proposed Structure with Different Substrates

This analysis may be employed as first step in order to obtain the approximate antenna substrate for proposed geometry. In this analysis we have taken four substrates Roger RT 5880 (Єr= 2.2), Roger TMM3 (Єr= 3.38), FR4 (*Єr*= 4.4) and Glass Epoxy (*Єr*= 4.7), resonance performance characteristic of these substrates is given in Table III. A graphical comparison of s-parameters for these substrates is shown in Fig. 4. It has been observed that with increase in the electrical permittivity of the substrate, input impedance decreases and the resonant frequencies shift towards lower side. The presented analysis also reveals that Roger TMM3 and FR4 substrate provides a better solution in terms of resonating characteristic for the proposed antenna, but to make it a cost effective solution FR4 may be consider as a better option.

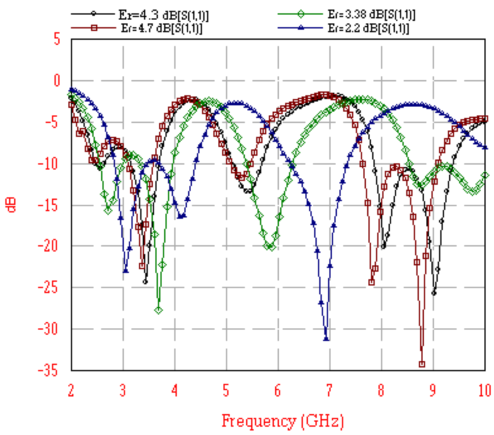


Fig. 4 Comparison of S-parameters with different substrates for 3rd iteration

TABLE III
RESONANT PERFORMANCE CHARACTERISTICS OF PROPOSED ANTENNA WITH DIFFERENT SUBSTRATES

Electrical Permittivity	Loss Tangent	Resonant Frequency (GHz)	Return Loss (dB)	Input Impedance (Ohms)
$\epsilon_r = 2.2$	0.0009	3.051	-23.0	57.6
		4.101	-16.48	62.23
		6.929	-31.21	51.47
$\epsilon_r = 3.38$	0.004	2.727	-15.83	37.09
		3.697	-27.85	53.98
		5.879	-20.12	41.7
		8.788	-12.78	77.59
		9.758	-13.48	76.69
$\epsilon_r = 4.4$	0.02	2.566	-10.77	27.91
		3.455	-24.37	48.79
		5.394	-13.47	32.51
		8.061	-20.19	55.64
		9.031	-25.74	55.20
$\epsilon_r = 4.7$	0.0008	3.374	-22.43	45.91
		5.313	-11.77	29.96
		7.818	-24.46	49.32
		8.788	-34.37	48.12

C. Optimization Results

The performance of the presented antenna depends on its electrical size, which is controlled by side of the rhombus. Towards the purpose of further widening the bandwidth of the proposed structure, side of the rhombus has been determined by means of BFO. To obtain a database from simulator for generating fitness function, the side of the rhombus has been varied from 15 mm to 25 mm with step size of 1.0 mm. The step size consider here is used to obtain the resonating parameters of the proposed antenna from the IE3D simulator after performing various simulations by varying the side of the antenna. The obtained results from the simulator provide a data base to form the fitness function for optimization of the antenna. The role of the BFO was to find the optimized value of the side of the rhombus which defines the best proposed structure for the wider bandwidth operation. This parameter was defined with suitable lower and upper bounds that gives one-dimensional solution spaces for which BFO searched for the optimal parameter of the proposed fractal structure. Then a fitness function was developed that gives a single number after taking the value of this parameter [11]. The following fitness function was formed to find the structure of the proposed antenna to work as per the requirement.

$$\text{Fitness function} = (7.0 - BW)^2 \qquad (6)$$

Fig. 5 shows the resonating parameters of the proposed structure with and without optimization. The comparative results shows that the optimized antenna (with optimum side of the rhombus a = 18 mm) achieved wider bandwidth with better resonating characteristics than its basic structure. The proposed geometry possesses 124.1% bandwidth ranging from 3.1 GHz to 10.0 GHz with -47.5 dB return loss at primary resonant frequency of 3.72 GHz. With these resonant properties the proposed antenna is feasible for various wireless and wearable antenna applications.

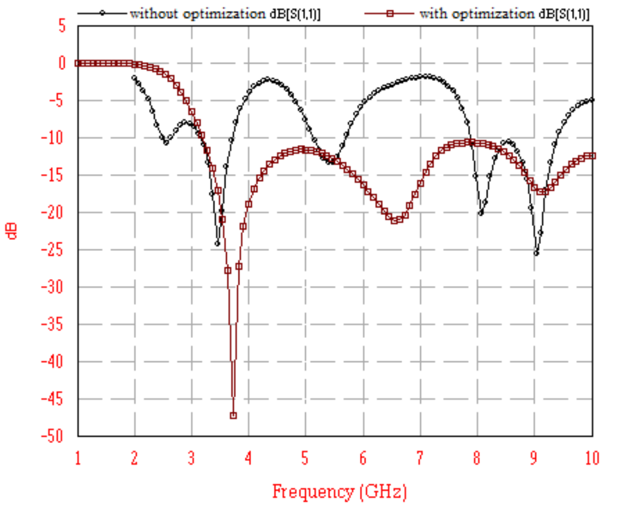


Fig. 5 Comparison of s-parameters with and without optimization

D. Radiation Pattern

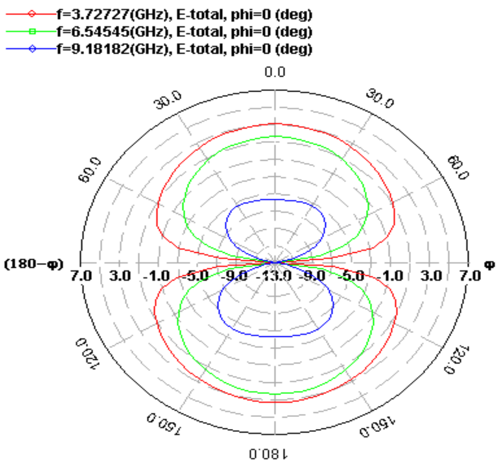
The radiation patterns of 3rd iteration in x-y and y-z plane are shown from Fig. 6. It is noted that proposed antenna possesses stable patterns throughout the whole frequency band. The patterns in x-y plane are in symmetry with antenna axis and patterns in y-z plane are nearly omnidirectional.

E. Gain

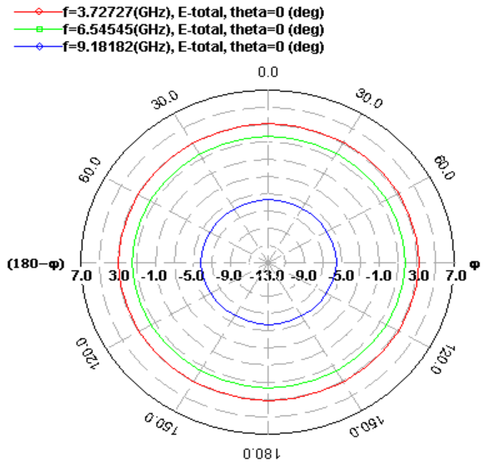
The simulated gain of the designed antenna is shown in Fig.7 which clearly indicates that maximum 4.41 dBi gain is achievable at 9.18 GHz resonating frequency for 3rd iteration. Gain at other frequencies is also considerable and can be observed from the Fig. 7.

IV. Conclusion

A rhombus shaped fractal antenna with multi and wideband characteristics for wearable electronic applications has been presented in this paper. The third iterations of the proposed fractal geometry leads to size reduction of about 13.08% of the base shape antenna without degrading its resonating behavior. Moreover, useful guidelines on the effect of different substrates on antenna characteristics have been adequately analyzed. An efficient BFO procedure has been employed to synthesize the proposed antenna in order to achieve wider bandwidth to make it feasible for wireless and wearable electronic applications.



(a)



(b)

Fig. 6 Simulated radiation patterns of optimized antenna (a) E-plane (b) H-plane

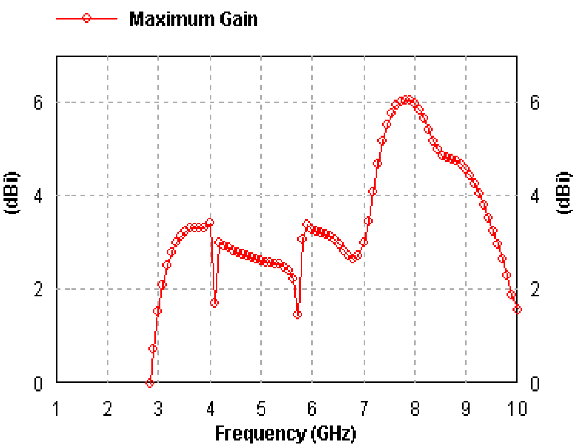


Fig. 7 Simulated Gain of optimized antenna

Acknowledgment

Authors are grateful to the Department of Electronics &

Communication Engineering of Sant Longowal Institute of Engineering & Technology (Deemed-University), Sangrur, Punjab, India, for providing excellent lab facilities.

REFERENCES

[1] S. Sankaralingam and B. Gupta, “Development of textile antennas for body wearable applications and investigations on their performance under bent conditions” *Progress in Electromagnetics Research B*, vol. 22, pp. 53-71, 2010.

[2] M. A. R. Osman, M. K. A. Rahim, N. A. Samsuri, H. A. M. Salim and M. F. Ali, “Embroidered fully textile wearable antenna for medical monitoring applications” *Progress In Electromagnetics Research*, vol. 117, pp. 321-337, 2011.

[3] A. Dierck, H. Rogier and F. Declercq, “A wearable active antenna for global positioning system and satellite phone” *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 2, pp. 532-538, 2013.

[4] C. A. Balanis, Antenna Theory (John Wiley & Sons, Inc. 1997).

[5] B. B. Mandelbrot, The Fractal Geometry of Nature (New York: Freeman, 1983).

[6] D. H. Werner and S. Ganguly, An overview of fractal antenna engineering research, *IEEE Antennas and Propagation Magazine*, vol. 45, No. 1, pp. 38-57, Feb 2003.

[7] L. Lizzi and G. Oliveri, “Hybrid design of a fractal-shaped GSM/UMTS antenna”, *Journal of. Electromagnetic Waves and Applications*, vol. 24, pp.707–719, 2010.

[8] L. Lizzi and A. Massa, “Dual-band printed fractal monopole antenna for LTE applications”, *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 760-763, 2011.

[9] S. Rani and A. P. Singh, “On the design and optimization of new fractal antenna using PSO”, *International Journal of Electronics*, vol. 100, no. 10, pp. 1383-1397, 2012.

[10] B. Mangaraj, I. Misra and A. Barisal, "Optimizing included angle of symmetrical V-dipoles for higher directivity using bacteria foraging optimization algorithm" *Progress in Electromagnetic Research B*, vol. 3, pp. 295-314, 2008.

[11] S. Rani and A. P. Singh, “A novel design of hybrid fractal antenna using BFO”, *Journal of Intelligent and Fuzzy Systems*, vol. 27, pp. 1233-1241, 2014.

[12] K. Passino, “Biomimicry of bacterial foraging for distributed optimization and control,” *IEEE Control Systems Magazine*, vol. 22, no. 3, pp. 52–67, June 2002.

[13] S. Rani and A. P. Singh, “Fractal antenna with defected ground structure for telemedicine applications,” *International journal on Communications, Antenna and Propagation*, vol.1, pp. 1-15, 2012.