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A Novel Antenna Design for Telemedicine Applications

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Abstract**—**To develop a reliable and cost effective communication platform for the telemedicine applications, novel antenna design has been presented using bacterial foraging optimization (BFO) technique. The proposed antenna geometry is achieved by etching a modified Koch curve fractal shape at the edges and a square shape slot at the center of the radiating element of a patch antenna. It has been found that the new antenna has achieved 43.79% size reduction and better resonating characteristic than the original patch. Representative results for both simulations and numerical validations are reported in order to assess the effectiveness of the developed methodology.

Keywords**—**BFO, electrical permittivity, fractals, Koch curve.

I. Introduction

THE growth of the telecommunication systems is driving the engineering efforts to develop wideband and compact systems. This has started antenna research in different directions, one of which is by using fractal shaped antenna elements [1]-[3]. The geometrical properties of self-similar and space filling nature has motivated antenna design engineers to adopt this geometry a viable alternative to meet the requirement of small size and multiband operation [4]. There are several techniques published so far to reduce the size of microstrip antenna such as shorting pins, introducing of U-slots, using substrates of high dielectric constant and fractal geometry [5]-[7]. Fractal geometry is a very good solution to this problem. In particular, afractal geometry based on a finite number of fractal iterations is useful to achieve a good miniaturization and to provide enhanced bandwidth [8]-[11]. Fractal antenna has useful applications in cellular telephone, microwave communications and Telemedicine [10]. Telemedicine can be defined as the delivery of health care and the sharing of medical knowledge over a long distance, using telecommunication means. It is very effective technique to deliver special health care in the form of improved access and reduced cost to the patients in rural areas [12]. The wireless telemedicine systems can provide better healthcare delivery, irrespective of any geographical barriers and mobility constraints [13].

During last decade, soft computing techniques have gained popularity among scientists and researchers in every branch of engineering. An alternative method known as BFO recently becomes popular for optimizing parameters in antenna and antenna array problems. The idea of BFO is based on the fact that natural selection tends to eliminate animals with poor foraging strategies and favor those having successful foraging strategies [14]. After various generations, poor foraging strategies are either eliminated or restructured in to good ones [15], [16]. In such a framework, this paper considers a modified Koch curve shape for synthesis of proposed antenna able to fully exploit the degree of the geometry under test. In order to assess the effectiveness of design process, various parameters are taken in to account and illustrative results are shown.

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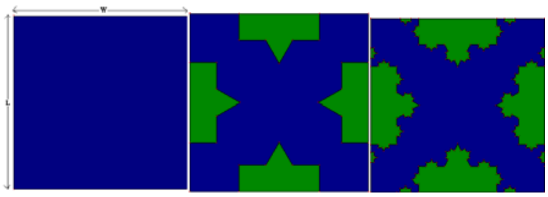
II. Antenna Design & Structure

Fig. 1 shows the simulated configuration of the proposed antenna with zero, first and seconder iteration order. The presented fractal geometry can be obtained by etching each side of the square patch by a modified Koch curve whose iteration factor is 1/5. The average electrical length of the patch increases with increase in the iteration numbers similar to the inductive and slot loading technique. In this paper only the first and the second iterations are considered since high order iterations do not make significant effect on antenna properties. Concerning the geometrical requirements, the maximum planar dimensions are set to 20x20 mm^2 on substrate of thickness 1.6 mm.



(a) (b) (c)

Fig. 1 Geometrical construction of proposed antennas (a) zero iteration (b) first iteration (c) second iteration

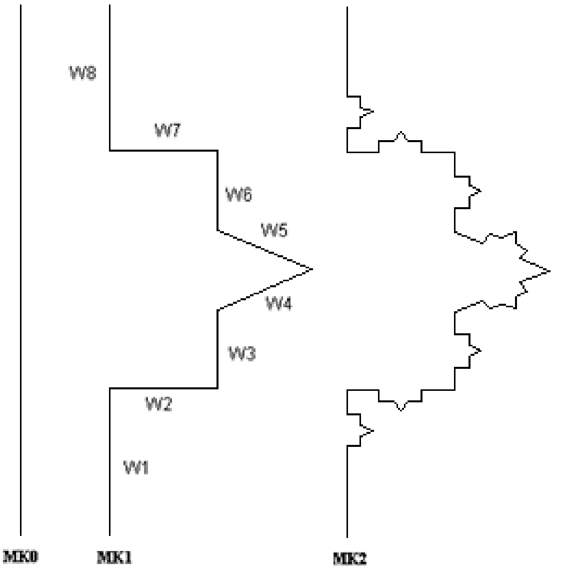


Fig. 2 Geometrical Description of Modified Koch Curve utilized in proposed antenna

A. Iterated Function Systems

The fractal shape utilized in this paper is a modified Koch curve as shown in Fig. 2, whose geometrical descriptors are obtained by Iterative Function System (IFS). IFS represent an extremely versatile method for wide variety of useful fractal structures. It has proven to be a very powerful design tool for fractal antenna engineers [3]. For self-affine fractal structure, the segments are developed at each iteration of same dimensions are derived using (1). IFS transformation coefficients for the proposed fractal antenna are given in Table I.

$$w(x,y)=\begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix}+\begin{bmatrix} e \\ f \end{bmatrix} \qquad (1)$$

TABLE I
IFS TRANSFORMATION COEFFICIENTS

w	a	b	c	d	e	f
1	1/4	0	0	1/4	0	0
2	0	1/6	-1/6	0	0	1/4
3	1/6	0	0	1/6	1/6	1/4
4	1/12	√3/12	-√3/12	1/12	1/6	5/12
5	1/12	-√3/12	√3/12	1/12	0.31	1/2
6	1/6	0	0	1/6	1/6	7/12
7	0	-1/6	1/6	0	1/6	3/4
8	1/4	0	0	1/4	0	3/4

B. BFO Implementation

The foraging optimization 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 [15]. 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. They assist during chemotactic progress by placing the bacteria to the nearest required values [16]. The input parameters for BFO are the number of bacteria in the population N_b, the chemotactic loop limit N_c, reproduction loop limit N_{re}, the elimination–dispersal loop limit N_{ed} and the probability of elimination–dispersal P_{ed}.

The pseudo code of BFO algorithmic is as follows [11]:

Step 1. Initialize input parameters.
Step 2. Create a random initial swarm of bacteria $\theta i(j, k,l)$, $\forall i$, $i = 1 \ldots S_b$.
Step 3. Evaluate $f(\theta i\ (j, k,l)), \forall i,\ i= 1 \ldots S$.
Step 4. Perform the chemotaxis for bacteria $\theta i(j, k, l)$.
Step 5. Perform the reproduction process by eliminating half the worst bacteria and duplicating the other half
Step 6. Perform the elimination-*dispersal* process for all bacteria $\theta i(j,k, l)$, $\forall i$, $i =1,\ldots.N_b$, with probability $0<\leq Ped\leq 1$.

III. RESULTS & DISCUSSIONS

A. Resonant Properties of Proposed Fractal Antenna

The simulation tool adopted for evaluating the performance of the proposed antennas is IE3D software, which is based on method of moments to solve the electric field integral equation. The shape modifications have been performed according to fractal shape erosion strategy in order to obtain the required resonant frequency and miniaturization. By etching modified Koch fractal shape along the edges of the patch, 34.79% size reduction has been achieved. It has been observed that with increase in iterations, resonating performance characteristics such as reflection coefficient, input impedance and VSWR has been improved considerably as given in Table II. Fig. 3 shows the s-parameters of proposed new fractal antenna and from the figure it is clear that among all the three iterations only second iteration is able to achieve resonance below -10 dB line.

TABLE II
RESONANT PERFORMANCE CHARACTERISTICS

No. of Iteration	Resonant Frequency (GHz)	Reflection Coefficient (dB)	Input Impedance (Ω)	VSWR
Zero	2.96	-4.27	16.57	4.14
First	3.04	-4.18	11.9	4.22
Second	3.06	-14.08	35.85	1.49

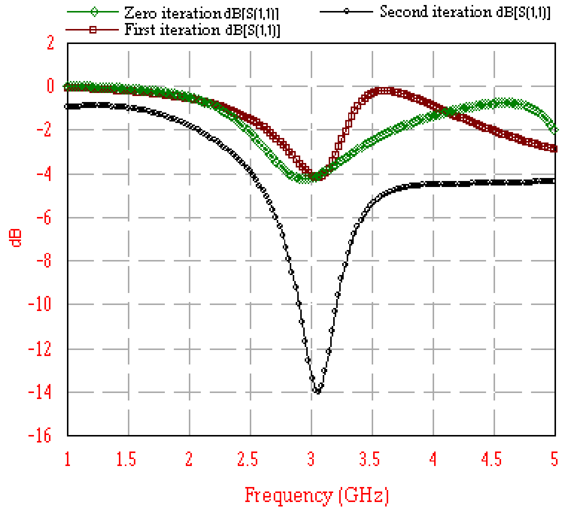


Fig. 3 Simulated s-parameters for all the three iterations

B. Input Impedance

A typical input impedance characteristic of the first three iterations for the proposed antenna is shown in Fig. 4. The input impedance is the ratio between voltages to the current at its terminals. Electromagnetic waves may encounter differences in impedance at each interface while traveling through the different parts of the antenna system, from the source to the feed line to the antenna and finally to the free space. And from the presented results, it is illustrated that with increase in iterations, the input impedance improved significantly.

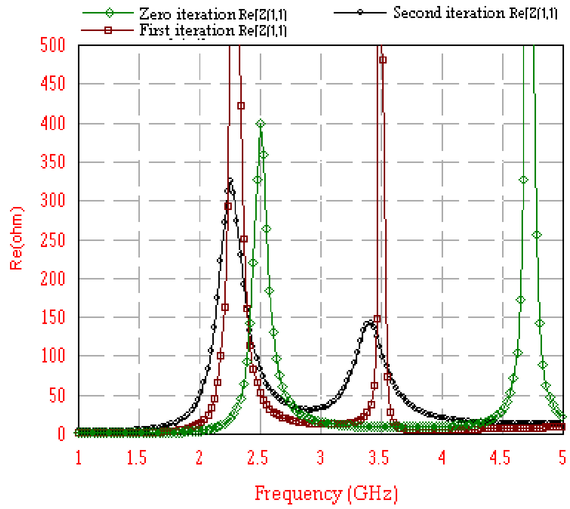


Fig. 4 Simulated input impedance for all the three iterations

C. Analysis of Proposed Antenna with Different Substrates

In order to satisfy both electrical and mechanical requirement for the antenna, an intelligent decision has to be taken during selection of the substrate. Table III give the simulated resonant properties of proposed structure with different substrates. It may be observed that except FR4 (ε_r= 4.4) all other presented substrates such as Duriod(ε_r= 2.2), Roger 4350 (ε_r= 3.48),Glass Epoxy (ε_r= 4.7),Glass (ε_r= 5.5) and Alumina (ε_r= 9.8) does not get any resonance below -10dB and having very poor resonating characteristics as shown in Fig. 5. The poor reflection coefficients suggest that the structure does not resonate. It may be notice that the resonating performance is more deteriorating from lower to higher electrical permittivity value. Based on these results it is observed that FR4 is best suitable substrate for the proposed structure.,

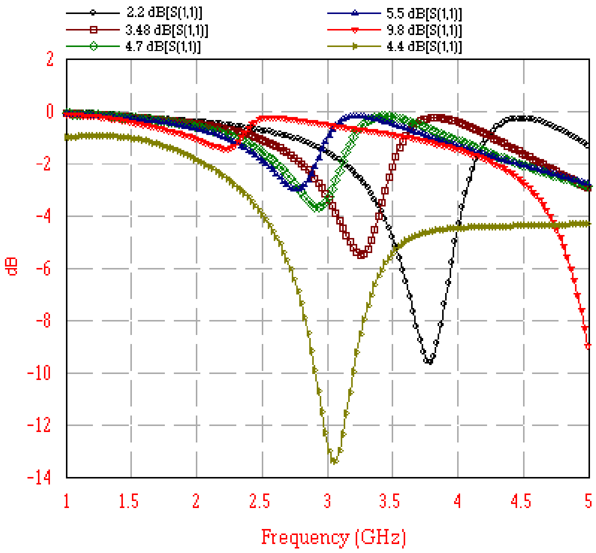


Fig. 5 Simulated s-parameters of the proposed fractal antenna with different substrates

TABLE III
RESONANT PROPERTIES OF PROPOSED ANTENNA WITH DIFFERENT SUBSTRATES

Electrical permittivity (ε_r)	Tangent Loss (tan δ)	Resonant Frequency (GHz)	Reflection Coefficient (dB)	Input Impedance (Ω)	VSWR
2.2	.0009	3.79	-9.61	25.15	1.98
3.48	.004	3.25	-5.49	15.31	3.26
4.4	.02	3.06	-13.38	35.67	1.54
4.7	.0008	2.93	-3.69	10.48	4.77
5.5	0	2.77	-3.00	8.59	5.83
9.8	.0002	2.23	-1.44	4.43	12.02

D. BFO Optimized Square Shape Slot in Center of Proposed Antenna

Towards the purpose of further miniaturization, a small size square shape slot has been made at the center of the proposed antenna whose geometrical descriptors are determined by means of BFO, as shown in Fig. 6. To obtain a database from simulator for generating fitness function, the dimensions of the center slot has been varied from 2 mm to 9 mm with step size of 0.5mm. The below given equation provide the values for analysis:

$$A = X + \sum_{i=1}^{n} i.x \tag{2}$$

where A is the side of square shape slot, x is the fractional change in the dimension of the slot and n is the number of steps.

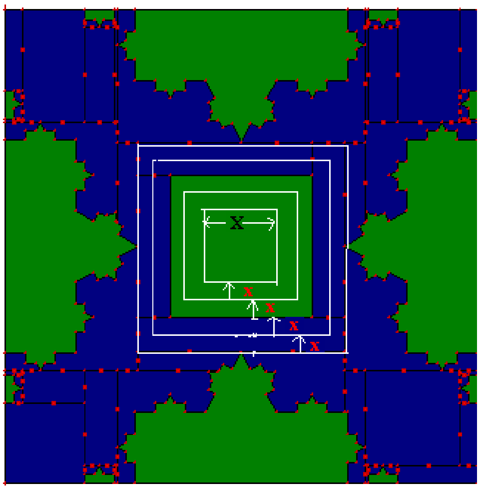


Fig. 6 Geometrical construction of proposed antenna having square shape slot at the center where white lines shows the fractional variation in the size of the slot

The role of the BFO was to find the optimized value of the side of the square slot which defines the best proposed structure for the specific frequency of 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 [14]. The following cost function was formed to find the structure of the proposed antenna to work at the required frequency.

$$\text{Fitness function} = (2.4 - f)^2 \tag{3}$$

Fig. 7 shows the resonating parameters of the proposed structure with and without optimization. The obtained results reveal that by introducing the optimal slot, size reduction of 9% has been achieved in addition to the size reduction due to insertion of fractal shape slot at the edges of the proposed antenna. Moreover this miniaturization has been obtained without degrading the resonating properties of the presented antenna. The proposed geometry resonates at required frequency of 2.4 GHz with reflection coefficient of -16.18dB.With these resonant properties the proposed antenna is feasible for wireless Telemedicine applications. The maximum achievable size reduction with the developed methodology is 43.79% for the proposed geometry.

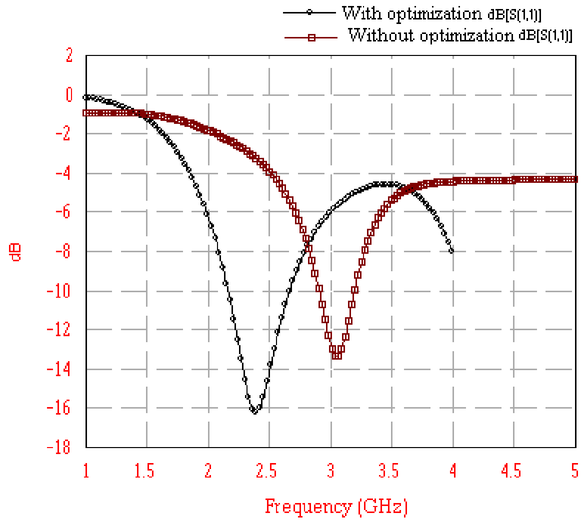


Fig. 7 Simulated s-parameters of the proposed fractal antenna with square slot

E. Current Distribution

One of the important parameter that needs to be analyzing during simulation is current distribution of the antennas. Fig. 8 shows the current distribution of the proposed antenna for the resonating frequency (2.4 GHz). By monitoring the current distribution or surface current, the effect of mutual coupling can be observed and this is important in order to minimizing coupling effect among the adjacent elements for the antenna design.

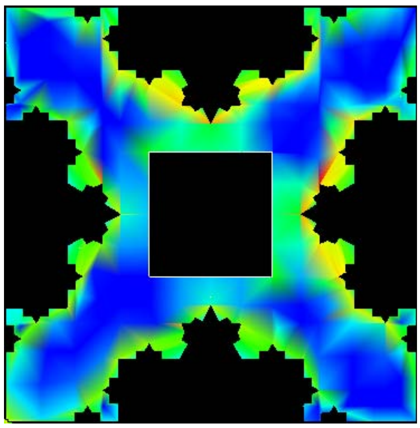
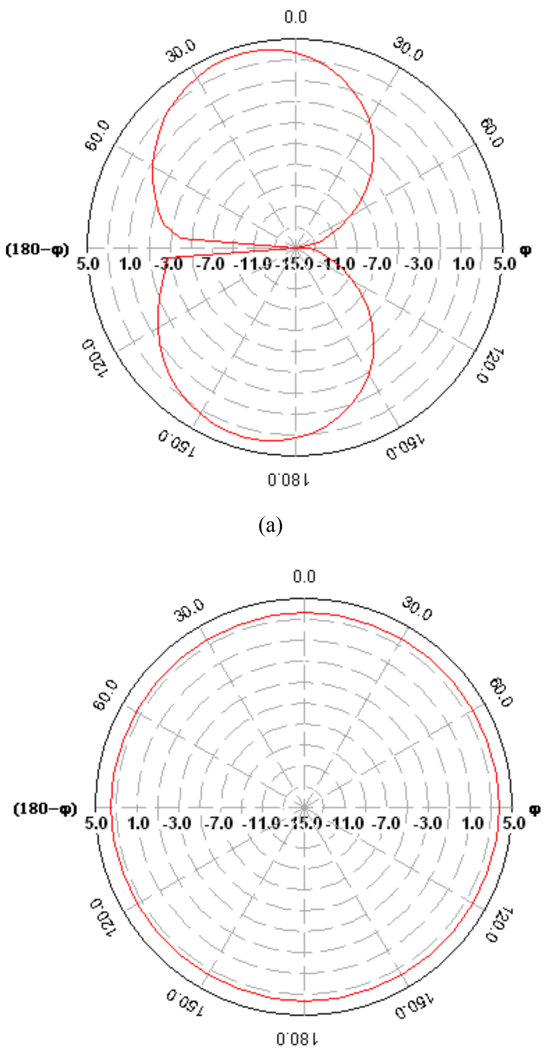


Fig. 8 Simulated current distribution at 2.4 GHz

F. Radiation Pattern

The radiation characteristics of proposed fractal antenna are shown from Fig. 9. The radiation pattern in E-plane is symmetrical to antenna axis whereas it has nearly omnidirectional pattern in H-plane.



(a)

(b)

Fig. 9 Simulated radiation pattern of proposed antennaat 2.4GHz (a) E-plane (b) H-plane

IV. Conclusion

The obtained results show that, a maximum of 43.79% patch size reduction is achieved by the proposed antenna, without degrading its resonating performances such as reflection coefficient, VSWR and input impedance. The essence of the size reduction technique is loading the inductive elements along the patch edges. The main advantages of the developed methodology are great size reduction, better resonating performance characteristics and easiness of design technique. The small size patches derived from this technique can be used in integrated low profile and low cost wireless Telemedicine applications successfully.

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