Bacteria Foraging Algorithm for Metamaterial Design and Optimization

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***Abstract*—Soft computing techniques are emerging as highly efficient global optimization techniques in the field of electromagnetics. These techniques along with the EM software have proved their efficiency in antenna engineering, wireless communication, absorber design and a few in the field of metamaterial structural analysis. Bacteria foraging algorithm, although has been used recently in controls, is still new to the field of metamaterial science and technology. In this paper, bacteria foraging algorithm (BFA) is used for design optimization of a double ring circular split ring resonator. Equivalent circuit analysis is used the EM tool for analysis of the CSRR. The aim of bacteria foraging algorithm is the estimation of structural parameters of the CSRR at a desired frequency range. Further the developed algorithm is proved through extraction of parameters of the optimized metamaterial structure. A comparative study with other soft computing techniques *w.r.t.* accuracy and computational time is provided.**

***Keywords*—BFA; metamaterial; split ring resonator; ECA**

I. INTRODUCTION

The emerging trends of soft computing techniques reveal that genetic algorithm has been employed extensively for diverse metamaterial applications [1]. In contrast, although particle swarm optimization (PSO) and bacteria foraging algorithm (BFA) are extensively used in control applications [2] but are new to the design and optimization of metamaterial applications. The authors of this paper have implemented PSO for design and optimization of a few metamaterial applications [3]. In this paper an effort has been made to study the feasibility of BFA in metamaterial design and optimization.

Split ring resonators are the building blocks of metamaterial design, which gives the negative refractive index at a particular resonant frequency. The resonant frequency of these structures depends on the structural parameters of the design such as width, diameter and separation of the ring and dielectric constant of the substrate as well. In this paper equivalent circuit analysis is used in conjunction with BFA for estimation of the design parameters of CSRR at a desired resonant frequency.

II. DESIGN AND OPTIMIZATION OF CSRR USING BFA

Bacterial foraging is a nature-inspired optimization technique based on population search of *E-Coli* bacteria present inside human intestine. This algorithm [4] was proposed by K. M. Passino in 2002, is more efficient for global search method. The workflow of this algorithm can be subdivided into four sections, namely, *chemotaxis*, *swarming*, *reproduction*, and *elimination-dispersal* [2].

BFA is implemented here to optimize the structural parameters of the CSRR at a desired frequency of operation. The solution approach with the cost function is in the subsequent section.

A. Circular CSRR

A The schematic of a circular SRR with the dimensions is shown in Figure 9a where r_{ext} is the external radius, w denotes the width of rings, d is the gap present between the rings and s represents the width of the split in the ring. In this method, the distributed network is converted to lumped network (Figure 1) and analysis is carried out.

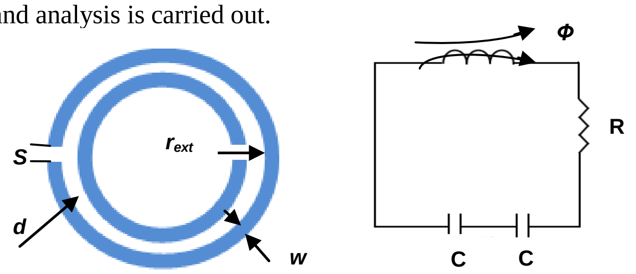

Fig. 1. Schematic of the double ring circular SSRR and its equivalent circuit

The resonant frequency for circular SRR is given by [3]

$$f_0 = \frac{1}{2\pi\sqrt{LC_S}} \quad (1)$$

where, L and C are the inductance and capacitance of the SRR respectively [5].

B. Problem Formulation

The efficiency and accuracy of implementation of BFA depends on the formulation of the cost function. The cost function used for this optimization is

$$f_{err} = \frac{|f_d - f_c|}{f_d} \quad (2)$$

where, f_d is the desired frequency and f_c is the calculated frequency obtained by equivalent circuit analysis.

The steps of BFA are followed for optimization of the cost function and the design parameters such as external radius of the CSRR, gap between the rings and width of the rings for a desired resonant frequency are obtained. These design parameters become input for simulation studied of various applications of metamaterial.

As BFA is new to the metamaterial science, a comparative study of the other techniques under this umbrella has been provided in Table I.

TABLE I. COMPARISON OF SOFT COMPUTING TECHNIQUES FOR OPTIMIZATION OF A CSRR AT 8.25GHZ (INTEL CORE,4 GB RAM)

Techniques	Accuracy (f_{error} in GHz)	CPU Time (in Sec)
BFA	**0.0181**	**0.058939**
PSO	0.0285	0.213547
Genetic Algorithm	1.5710	0.226509

The feasibility study shows that BFA is more efficient in terms of accuracy and CPU time. It is important to mention here that the accuracy and CPU time of all these above mentioned soft computing techniques depends on the parameter selection and depends on type and complexity of the problem.

Towards proof of concept of the algorithm implemented, simulation studies of a CSRR are carried out, using the estimated design parameters obtained from BFA. The simulation results and the extracted permittivity and permeability graphs are given in the next section.

III. SIMULATION RESULTS OF CSRR

Let us assume that the objective is to design a metamaterial circular ring SRR (Fig. 2) having resonant frequency 4.5 GHz, dielectric constant of the substrate as 3.8 and height of the substrate as 2.4mm. The CAD package provides the outputs as external radius *r* =2.7mm, width of the ring *w* =0.3mm, and gap in the rings *g* = 0.3mm. After obtaining the structural parameters the simulation studies were carried out and the corresponding permittivity and permeability (Fig. 3) has been extracted [4]. The simulation result (Fig. 4) show that the designed metamaterial circular ring SRR has negative permeability at resonant frequency 4.5 GHz, which fulfils the design objective.

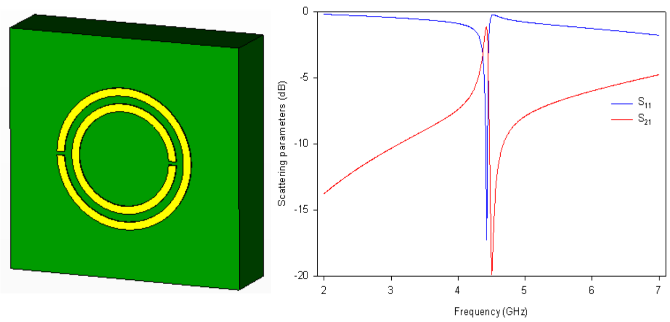

Fig. 2. The designed double ring CSRR and corresponding scaterring parameters

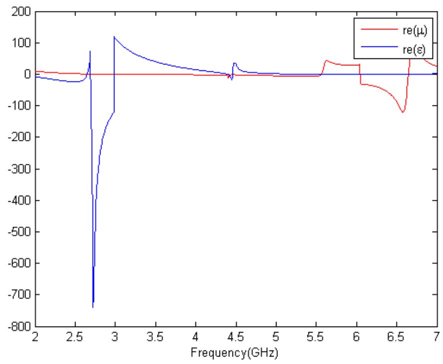

Fig. 3. The extracted permittivity and permeability of the designed CSRR

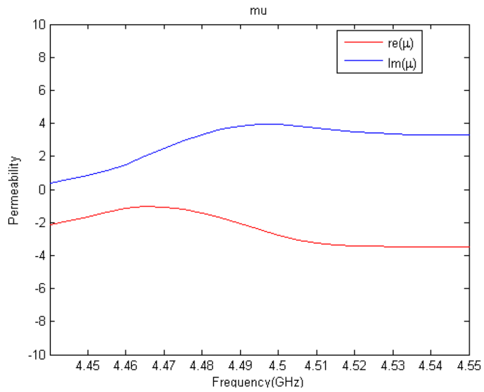

Fig. 4. The negative permeability at the desired resonant frequency (4.5GHz)

IV. CONCLUSION

In this work, bacteria foraging algorithm is implemented for design and optimization of metamaterial structures. BFA in conjunction with equivalent circuit analysis method is used for estimation of the design parameters of a double ring circular split ring resonator. The estimated design parameters are used as input for simulation studies and the permittivity and permeability of the metamaterial structure has been extracted. This work will be a module for design of BFA based CAD packages metamaterial structures.

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