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ANALYSIS OF MAGNETICALLY BIASED MICROSTRIP EQUILATERAL TRIANGULAR PATCH ANTENNA ON FERRITE SUBSTRATE USING GA

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Abstract

A Theoretical analysis by Genetic Algorithm for optimization of important parameters (Directivity, Radiation Power, Impedance etc.) of magnetically biased microstrip antenna fabricated on ferrite substrate is reported. The effect of magnetic field (H_o) on ferrite antenna during electromagnetic propagation is incorporated in function analysis with the help of extraordinary propagation constant (k), which is new one in this type of optimizing analysis. Functions for the fitness of the GA program is developed using cavity model of the analysis of microstrip antenna. The genetic algorithm was run for 500 generations. The probability of crossover was varied from 0.7 to 0.85 and the probability of mutation was varied from 0.001 to 0.002. The computed results are in good agreement with the results obtained experimentally.

Keywords:

Genetic algorithm;
Magnetically biased;
Cavity model;
Equilateral triangular ferrite microstrip antenna;

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I. INTRODUCTION

Microstrip patch antennas of all shapes are widely used in communication systems where their small size, conformal geometry and low cost can be used to advantage. Due to the recent availability of low loss commercial microwave ferrites, there is an increasing interest in the performance of the patch antennas printed on ferrite substrates in the effect of external dc-magnetic field. External magnetic field makes the patch antennas very versatile in the sense of scanning without mechanical movement, low RCS and also bandwidth enhancement [12-17].

Although some work [1-6] have been performed for microstrip antenna with GA approach for the patch antennas without magnetic biasing but analysis of almost all important parameters for ferrite substrate under magnetic biasing for circular patch antenna is new one. Present analysis also incorporate the dispersion effects due to magnetic field biasing in the form of effective propagation constant (k) which is not discussed in the referenced articles. Some similar referenced works [7-11] also have done mathematically or by conventional methods for optimization but this technique is rather precise, accurate and sensitive to optimize parameters of patch antenna as well as other type of antenna also.

There are many optimization techniques frequently using for the same work for example Broyden–Fletcher–Goldfarb–Shanno (BFGS), Davidon–Fletcher–Powell (DFP), Nelder–Mead downhill simplex (NMDS), Steepest descent, etc. GA was introduced by Holland [24] and was applied to many practical problems by Goldberg [25, 26]. It is well known that search technique, the genetic algorithm is a parallel, robust and probabilistic search technique that is simply and easily implemented without gradient calculation, compare with the conventional gradient base search procedure. Most important of all, the GA proposed also provides a mechanism for global search that is not easily trapped in local optima. The GA proposed here an adaptive mutation rate strategy [28-29].

II. GENETIC ALGORITHM

Genetic Algorithm (GA) is one of the stochastic based search methods that can handle easily the common electromagnetic characteristics which compare to other optimization techniques. It has several advantages over the traditional numerical optimization. It includes the facts that it can optimize with continuous or discrete parameters, doesn't require derivative information. It can works with a large number of variables, well suited for parallel computers, provides a list of optimum parameters not just a single solution. Even it can works with numerically generated data, experimental data, or analytical functions. GA can solve some specific mathematical electro-magnetic problems which cannot be handled by other optimization techniques like hill climbing method, indirect and direct calculus based methods, random search methods etc. Actually it is mathematical and probabilistic algorithm which based or made for a biological part of human beings known as chromosome which is studied in subject the Genetics.

This algorithm begins with a large list of randomly generated chromosomes. Cost function is evaluated for each chromosome. The populations which are able to reproduce best fitness (desired fitness) are known as parents. Then the GA goes into the production phase where the parents are chosen by means of a selection process. The selected parents reproduce using the genetic algorithm operator called crossover. In crossover random points are selected. When the new generation is complete, the process of crossover is stopped. Mutation has a secondary role in the simple GA operation. Mutation is needed because, even though reproduction and crossover effectively search and recombine extant notions, occasionally they may become overzealous and lose some potentially useful genetic material. In simple GA, mutation is the occasional random alteration of the value of a string position. When used sparingly with reproduction and crossover, it is an insurance policy against premature loss of important notions. Mutation rates are of the order of one mutation per thousand bit transfers. According to the probability of mutation, the chromosome are chosen at random and any one bit chosen at random is flipped from '0' to '1' or vice versa. After mutation has taken place, the fitness is evaluated. Then the old generation is replaced completely or partially. This process is repeated. After a while all the chromosome and associated fitness become same except for those that are mutated. At this point the genetic algorithm has to be stopped [6, 8-10].

III. STRUCTURE & THEORY OF ANTENNA

Structure of microstrip equilateral triangular patch antenna is depicted in fig. 1. Here 'a' and 'a_e' are the equilateral side and effective equilateral side of microstrip patch respectively. Patch is modeled on LiTi ferrite substrate of thickness 'h'. The dielectric constant and saturation magnetization ($4\pi M_s$) of substrate is 17.5 and 2200 Gauss respectively.

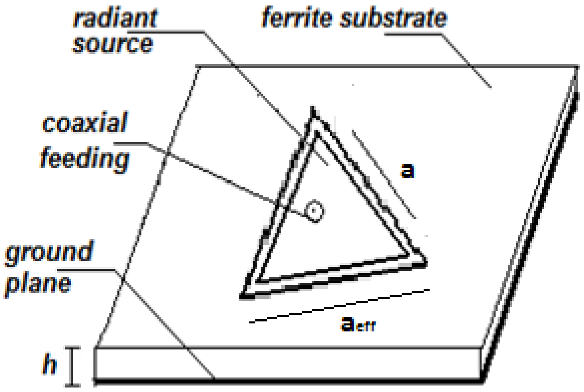

Fig. 1: Schematic Diagram of Microstrip Equilateral Triangular Patch Antenna

It has been established that, for a biased ferrite slab, a normal incident plane wave may excite two types of waves (ordinary and extraordinary wave). In the case of normal incident magnetic field biasing ordinary wave is same as the plane wave in the dielectric slab. On the other hand, the extraordinary wave is a TE mode polarized parallel to the biasing direction with its phase propagation constant K_e [13, 16, 30].

$$K_e = \frac{w}{c}\sqrt{\epsilon_{eff} \times \mu_{eff}} \tag{1}$$

$$K_d = \frac{w}{c}\sqrt{\epsilon_{eff}} \tag{2}$$

$$\mu_{eff} = \frac{\mu^2 - k^2}{\mu} \tag{3}$$

$$\mu = 1 + \frac{w_o w_m}{w_o^2 - w^2} \tag{4}$$

$$k = \frac{w w_m}{w_o^2 - w^2} \tag{5}$$

where

$$w_o = \gamma H_o \;\; and \;\; w_m = \gamma 4\pi M_s$$

where H_o is the bias field, $4\pi M_s$ is the saturation magnetization, γ is the gyromagnetic ratio as $\gamma = 2.8\, MHz./Oe$. To obtain good performance, there are many feeding methods, such as CPW in the ground feeding microstrip antenna, and CPW with stub patch feeding slot antenna. Considering impedance matching of patches coaxial feeding is generally preferred [31]. Thus the far zone expressions for equilateral triangular patch microstrip antenna are obtained as follow:

$$R_E(\theta) = \eta_o^2 \omega^2 (\,|F_Y|^2 + |F_X|^2) cos^2\theta \tag{6}$$

$$R_H(\theta) = \eta_o^2 \omega^2 (\,|F_X|^2 + |F_Y|^2) cos^2\theta \tag{7}$$

where

$$\boldsymbol{k} = K_{\pm} = K_d \left(\frac{w_o + w_m \mp w}{w_o \mp w_m}\right)^{1/2}$$

Here F_X and F_Y are the vector potential components in the rectangular coordinate system.

IV. APPLICATION OF GENETIC ALGORITHM TO THE MICROSTRIP ANTENNA AND COMPUTED RESULTS

All the vital parameters like thickness of the substrate, bias magnetic field, equilateral length, dielectric constant etc. were coded into 5 bit scaled binary coding as the requirement of fitness function. The Roulette wheel selection was used for GA population. The genetic algorithm was run for 500 generations. The probability of crossover was varied from 0.7 to 0.85 and the probability of mutation was varied from 0.001 to 0.002. The fitness functions expressions of antenna used for optimization are [29]:

- **Fitness Function:1-** Effective Equilateral Length

$$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_{reff}}} \tag{8}$$

where

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{a}\right)^{-\frac{1}{2}}$$

- **Fitness Function:2-** Radiation Power

$$P_{Rad} = \frac{1}{4\eta_o}\int_0^{2\pi}\int_0^{\pi}\left[\begin{matrix}\left(|E_\theta|^2 + |E_\varphi|^2\right)\\ \times r^2 sin\theta\, d\theta d\varphi\end{matrix}\right] \tag{9}$$

- **Fitness Function:3-** Directivity

$$D_g = \frac{W}{\lambda} \times \left(\frac{2}{15 \times 2\, P_{rad}} \right) \tag{10}$$

- **Fitness Function:4-** Input Impedance

$$Z_{in} = \frac{1}{(4 \times Prad)} \tag{11}$$

- **Fitness Function:5-** Quality Factor

$$Q_t = \frac{1}{Q_r} + \frac{1}{Q_d} + \frac{1}{Q_c} \tag{12}$$

where

$$Q_r = \frac{2\pi}{P_{rad}}$$

$$Q_d = \frac{1}{LT}$$

$$Q_c = h \times (\pi\, f\, \mu\, \sigma)^{1/2}$$

- **Fitness Function:6-** Bandwidth

$$B = \frac{(s-1)}{\left(Q_t \times (s^{1/2})\right)} \tag{13}$$

The antenna parameters are characterized by a particular of combination of input variables like dielectric constant, patch side length and substrate thickness of the ferrite which is determined using cavity model.

V. RESULTS AND CALCULATIONS

Obtained Graphs (fig. 2-6) shows the variation of best, mean and expected values of radiation power of antenna. During calculation at every generation calculate expected value, mean and best value, then plot them for the corresponding parameter fitness functions.

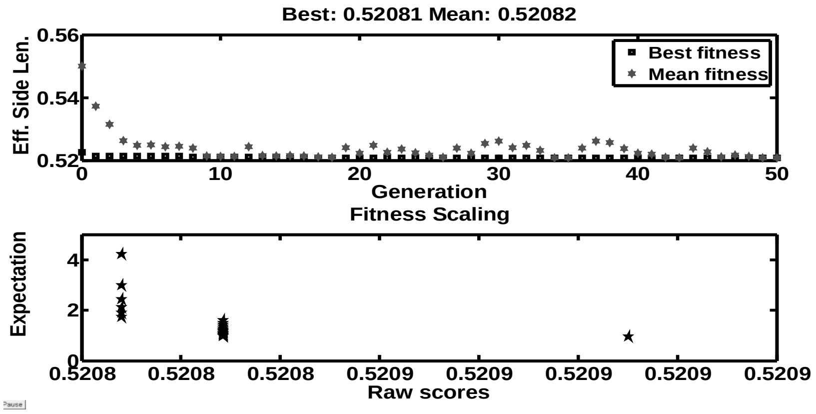

Fig. 2: Variation of Best, Mean and Expected value of Eff. Side Length of Equilateral triangular Patch Antenna

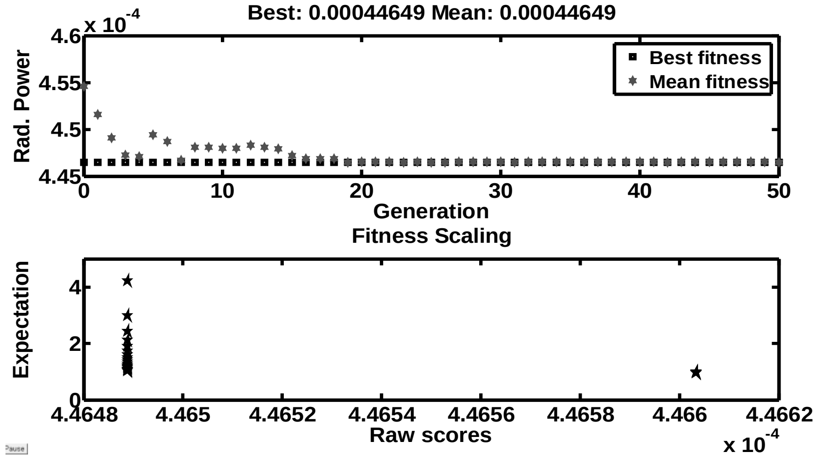

Fig. 3: Variation of Best, Mean and Expected value of Radiation Power of Equilateral triangular Patch Antenna

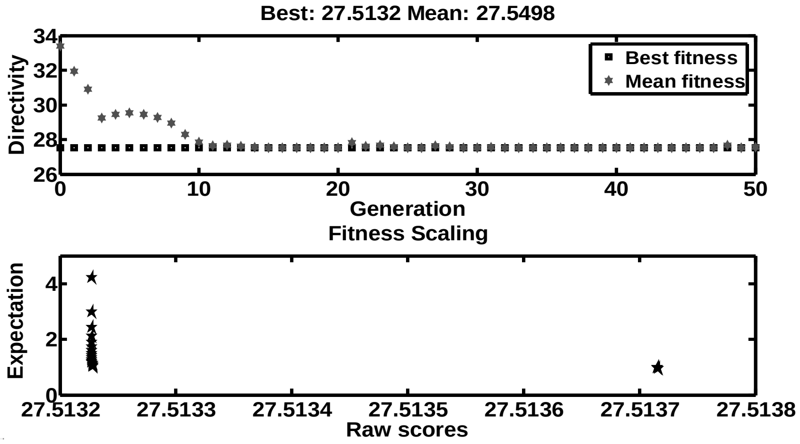

Fig. 4: Variation of Best, Mean and Expected value of Directivity of Equilateral triangular Patch Antenna

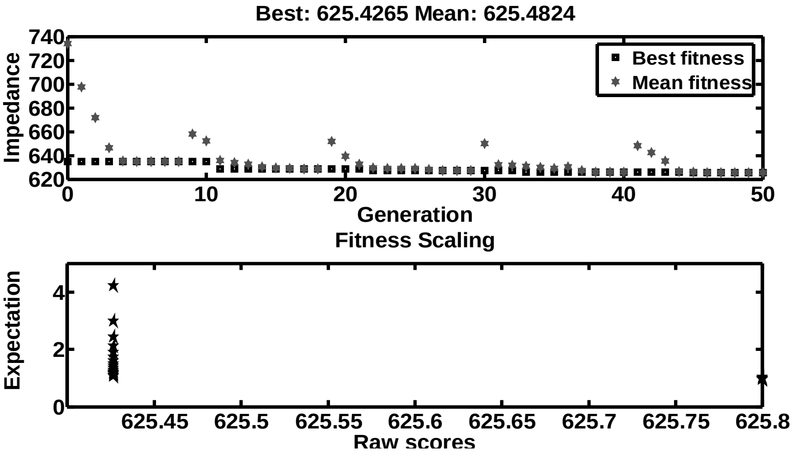

Fig. 5: Variation of Best, Mean and Expected value of Input Impedance of Equilateral triangular Patch Antenna

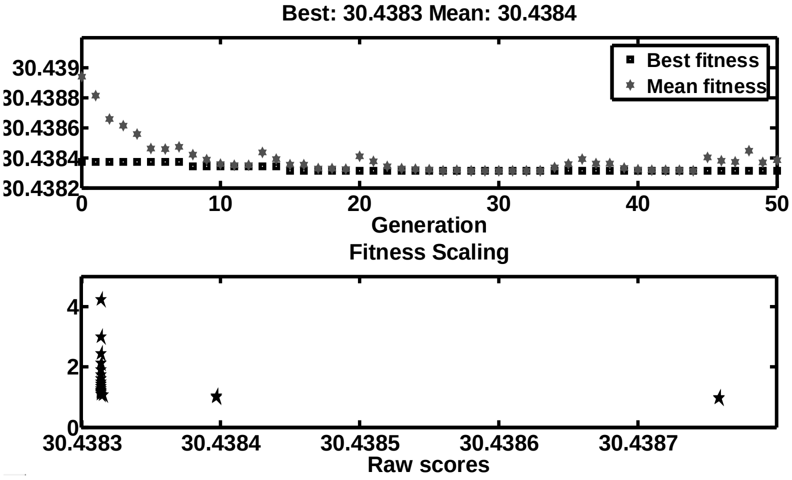

Fig. 6: Variation of Best, Mean and Expected value of Quality Factor of Equilateral triangular Patch Antenna

Every graph has a certain generation points above which convergence become very slowly and variation among mean and best values become negligible. All graphs (fig. 2-6) shows the appreciate variation in mean values but in best value, carry a very little variation due to big generation attempt which precise or accurate the desired result. This big generation amount (500) has been applied to removing the inaccuracy in the best result which can be judge by expected value graphs shown in every figure.

The performance graph (fig. 5, 6) of Input impedance and quality factor shows a little bit variation in best value, which shows the requirement of more generation attempt but could not be performed due to inefficiency of computer program. Calculated values of parameters of microstrip circular patch antenna with GA program have been compared with some theoretical and experimental results obtained by other methods and referenced in the research articles [18-26], which are in good agreement and given in table 1.

Table 1: Comparison of Parameters Calculated by GA Program and Experimentally Obtained.

Parameters	**Opt. Values**	**Exp. Values**
Eff. Side Length	0.5208 cm	0.5100 cm
Rad. Power	0.4464 mW	0.4025 mW
Directivity	27.51 dB	20.50 dB
Impedance	625.42 ohms	525 ohms
Quality Factor	30.43 dB	35.44 dB

CONCLUSION

Designing the antenna with the optimum values of parameters over a given frequency range is an example of an optimization problem. The GA is very precise and fast compare to other techniques because it encodes the parameters then the optimization is done with the encoded parameters. To design an antenna with best performance first, the problem should formulated for the size, shape, and material properties associated with the antenna. Next, an appropriate mathematical description that exactly or approximately models the antenna and electromagnetic waves should apply. Finally, numerical methods are used for the solution. One problem has one solution. Finding such a solution has proved quite difficult, even with powerful computers.

Rather than finding a single solution, optimization implies finding many solutions then selecting the best one. Optimization is an inherently slow, difficult procedure, but it is extremely useful when well done. The difficult problem of optimizing an electromagnetics design has only recently received extensive attention.

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