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Application of Genetic Algorithm to the Optimization of Gain of Magnetized Ferrite Microstrip Antenna

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Abstract- **The application of Genetic Algorithm (GA) to the optimization of gain of microstrip antenna, fabricated on ferrite substrate, biased externally by a steady magnetic field, is reported. The fitness function for the GA program is developed using cavity method for the analysis of microstrip antenna. The computed results are compared with the results obtained using GA optimizer of MATLAB.**

Index Terms- **cavity method, circular ferrite microstrip antenna, gain, Genetic algorithm, magnetically biased.**

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. Ferrite is a ferromagnetic material with a significant amount of anisotropy at microwave frequencies. These materials are inherently non reciprocal under dc bias magnetic field whose permeabilty tensor and the elements of the tensor can be controlled by changing the bias magnetic field.

Microstrip patches, fabricated on ferrite substrates, have a number of novel properties which are not found with normal dielectrics substrates. The high permittivity of the unbiased ferrite reduces the patch dimension allowing miniaturization[1-3]. In a magnetic biased state, patches on ferrite exhibit frequency agility, pattern control and low radar cross section [4-11]. The longitudinally magnetized ferrite microstrip antennas (FMSA) are useful to obtain circular polarization using single feed, switchable between LHCP and RHCP. These kinds of antennas can be used for dual frequency operation and the operating frequencies can be tuned adjusting the bias magnetic field which cannot be achieved using microstrip antennas fabricated on dielectric substrates [12-15]. In fact, in satellite communications with mobiles, a single antenna which radiates circularly polarized fields would be interesting. Since the magnetized FMSA can generate dual frequencies with opposite polarizations the level of magnetization is very important for impedance matching of the antenna. It is found by theoretical and experimental investigations [12-15] that if the FMSA is magnetized above saturation, in most of the cases, impedance levels at the two resonance frequencies are unequal and practically it is not possible to match the impedances at both the frequencies. But if the FMSA is magnetized below saturation (partially magnetized), in most of the cases, impedance levels at the two resonance frequencies are equal and practically it is possible to match the impedances at both the frequencies. For this reason, in this paper, FMSA is assumed to be magnetized below saturation magnetization.

At a particular resonance frequency, the gain of a microstrip antenna, fabricated on a dielectric substrate, depends on the dimensions of the patch, relative dielectric constant and thickness of the substrate, when it is excited at the impedance matched position. But in the case of a microstrip antenna fabricated on a ferrite substrate and magnetized by a d. c. magnetic field, in addition to the above parameters, the antenna gain also depends on the bias magnetic field and the saturation magnetization of the ferrite. Thus the gain of a magnetized FMSA is a function of large number of parameters and hence the optimization of gain is important. This paper describes the application of Genetic Algorithm to optimize the

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gain of magnetized circular ferrite microstrip antenna. Genetic Algorithm is a class of search techniques that use the mechanisms of natural selection and genetics to conduct a global search of the solution space [16] and this method can handle the common characteristics of electromagnetics [17-20]. Genetic algorithm has been chosen as the optimization tool in this paper to optimize the search for the dimension of the patch , external magnetic bias in order to achieve the optimized gain. The function of gain is an implicit expression of its dimensions, dielectric constant and permeability tensor of the ferrite material used. Hence, GA offers a strong means to facilitate the search and get the desired optimized values. The circular patch microstrip antenna was modeled using the cavity method of analysis and the fitness functions to optimize the gain and efficiency were obtained. The Genetic Algorithm program, for the optimization of magnetized FMSA, is developed using C++ language. In this case, antenna was assumed to be operating in the fundamental TM11 mode. Optimization of gain, using GA, was done for many values of saturation magnetization for different ferrite materials having different dielectric constant and substrate height. The optimized results using GA program are compared with the results obtained using MATLAB.

II. GENETIC ALGORITHM

Genetic Algorithm (GA) is a robust stochastic based search method that can handle the common characteristics of electromagnetics which can not be handled by other optimization techniques like hill climbing method, indirect and direct calculus based methods, random search methods etc. A chromosome in a computer algorithm is an array of genes. Each chromosome has an associated cost function assigned to the relative merit. The algorithm begins with a large list of randomly generated chromosomes. Cost function is evaluated for each chromosome. Genes are the basic building blocks of a genetic algorithm. A gene is a binary encoding of a parameter. The population which is able to reproduce best 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.

III. THEORY

Magnetized circular FMSA is shown in the fig .1. The geometry consists of a circular metallic patch on a circular ferrite substrate backed by a metallic ground plane. The ferrite substrate is axially biased by a steady magnetic field H_o ,along the positive z-axis. When a ferrite medium is biased by a steady magnetic field, its permeability (μ) assumes a tensor for microwave signal. The total alternating magnetic flux density **B** and a time-varying a. c. magnetic field **H** is related by the equation **B** = [μ] **H**. In this paper, the ferrite is assumed to be partially magnetized by a d. c. magnetic field. Under dc magnetic bias the permeability tensor for a partially magnetized (that is, below saturation) ferrite is given by [11, 22]

$$[\mu] = \begin{vmatrix} \mu & -jk & 0 \\ jk & \mu & 0 \\ 0 & 0 & \mu_z \end{vmatrix} \mu_0 \qquad (1)$$

Where, $\omega_0 = 2\pi\Gamma H_0$ $\qquad \omega_m = 2\pi\Gamma(4\pi M_s)$

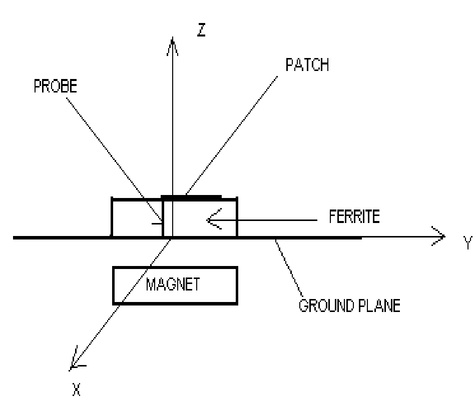

Fig1. Magnetized Ferrite Microstrip Antenna

$$k = -\frac{\omega\omega_m}{\omega_0^2 - \omega^2}, \qquad \mu = 1 + \frac{\omega_0\omega_m}{\omega_0^2 - \omega^2},$$

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

Here, μ and k are the elements of the permeability tensor[22] which are complex quantities, μ_{eff} is the effective permeabilty, Γ is the gyromagnetic ratio=2.8MHz/Oe and H_o is the bias steady magnetic field (Oersted) and $4\pi M_s$ is the saturation magnetization of the ferrite sample and ω is the circular frequency of operation corresponding to the frequency *f*.

The circular microstrip antenna configuration (shown in fig.1) can be modeled as a cylindrical cavity, bounded at its top and bottom by electric walls and on its sides by a perfect magnetic wall. Due to fringing fields from the edges of the patch, there is small extension of the dimensions of the patch. The z-directed electric field inside the cavity, which is assumed to be independent of the z-direction (because the height of the cavity along the z-axis is equal to the substrate thickness which is much less than the dimensions of the cavity along radial direction) and in the cylindrical co-ordinate (ρ, θ, ø) for TM modes of propagation, can be written as[12,13]

$$E_z(\rho,\phi) = E_0 J_n(\gamma\rho) e^{jn\phi} e^{j\omega t} \qquad (2)$$

Here, the circular FMSA of radius *'a'*, is biased by a steady magnetic field and $J_n(\gamma p)$ is the Bessel function of order 'n' and $\gamma^2 = \omega^2 \varepsilon_r \mu_{eff} \varepsilon_0 \mu_0$ where ε_r, ε_0 and μ_0 are relative dielectric permittivity of the ferrite substrate, free-space permittivity and free-space permeability respectively.

In an infinite magnetized ferrite medium the eigenmodes are circularly polarized. The positive values of 'n' in the above equation gives left circular polarization and the negative values of 'n' gives right circular polarization. The dielectric constant and substrate thickness of the microstrip substrate are ε_r and 'h' respectively. The resonance frequency can be obtained by applying magnetic wall boundary condition and for fundamental TM_{11} mode can be expressed as [11],

$$f_r = \frac{1.84118c}{2\pi a_e\sqrt{\varepsilon_{eff}\,\mu_{eff}}} \qquad (3)$$

The expressions for effective dielectric constants ε_{eff} and effective radius of the patch a_e can be found in [21] and *'c'* is the free-space velocity of light. In the cavity model, from the tangential fringing electric field, magnetic current around the edges of the patch is determined and from this magnetic current far field components are calculated. The far field components for a magnetized FMSA are circularly polarized and the far field components are functions of bias magnetic field [12-14]. The expression for directivity of the circular ferrite microstrip antenna reduces to

$$D = \frac{8}{I_p} \qquad (4)$$

here,

$$I_p = \int_0^\pi \left[\{J_{n+1}(x) - J_{n-1}(x)\}^2 + \cos^2\theta\{J_{n+1}(x) + J_{n-1}(x)\}^2 \sin\theta d\theta\right] \qquad (5)$$

where $x = k_0 a \sin\theta$ and

$$k_0 = \frac{2\pi f\sqrt{\varepsilon_{eff}}}{c} \qquad (6)$$

The gain of the circular FMSA is,

$$G = \eta D \qquad (7)$$

where η is the efficiency of the antenna which is obtained by calculating radiation loss, dielectric loss, conductor loss and magnetic loss. This expression of gain of the FMSA is used as the fitness of GA optimization.

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

The magnetized ferrite circular patch microstrip antenna is assumed to be operating at TM_{11} mode. All the parameters, that is, the, thickness of the patch ,bias magnetic field and the value of the dielectric constant were coded into 5 bit scaled binary coding. Hence the total length of the chromosome was 15 bits. The Roulette wheel selection was used for GA population. The genetic algorithm was ran for 500 to 1000 generations. However after 600 generations the convergence is very slow. 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 function used for optimization is the expression of antenna Gain or G(X) (eqn.7) of antenna X at frequency at which the antenna is being optimized. The antenna 'X' is characterized by a particular of combination of input variables like dielectric constant and substrate thickness of the ferrite, saturation magnetic field, bias magnetic field which is determined using cavity model analysis of magnetized FMSA at TM_{11} mode. The flow chart, for optimization of microstrip antenna, using GA, is is shown in fig. 2.

The variation of gain of magnetized ferrite circular micrpstrip antenna with number of generation, obtained using GA program is compared with that obtained using MATLAB and shown in fig.3.

In MATLAB program, the fitness function was obtained using cavity method of magnetized ferrite microstrip antenna. The simplicity and fairly good accuracy of cavity method is advantageous for MATLAB optimizer compared to numerical techniques. In figure 3, the plots are shown for magnetized ferrite material having constant saturation magnetization ($4\pi M_s$ =900Gauss). The range of the Ho, dielectric constant and height were varied from 100 to 800 Orested, 12 to 15 and 1 to 3mm respectively. The ferrite,YIG Garnet, with dielectric constant 14.3 and saturation magnetization of 900 Gauss is available. The value of Ho was found to be 100 Orested for which actual radius of the patch is 6.8517 mm at frequency of 3 GHz. The optimized value was obtained at generation number 561. The maximum value for gain is 5.35dB. The dielectric constant and and height of the substrate at this maximum gain was 14.3 and 1.79 mm. The variation of gain of FMSA with bias magnetic field is shown in fig.4 at 3GHz, and for same material as in figure 3 and with $4\pi M_s$ =900Gauss. In figure 4, the range of the Ho, dielectric constant and height were varied from 330 to 830 Orested, 12 to 15 and 1mm to 3mm respectively. The results, shown in figure 3 and figure 4 are for n=+1 mode.

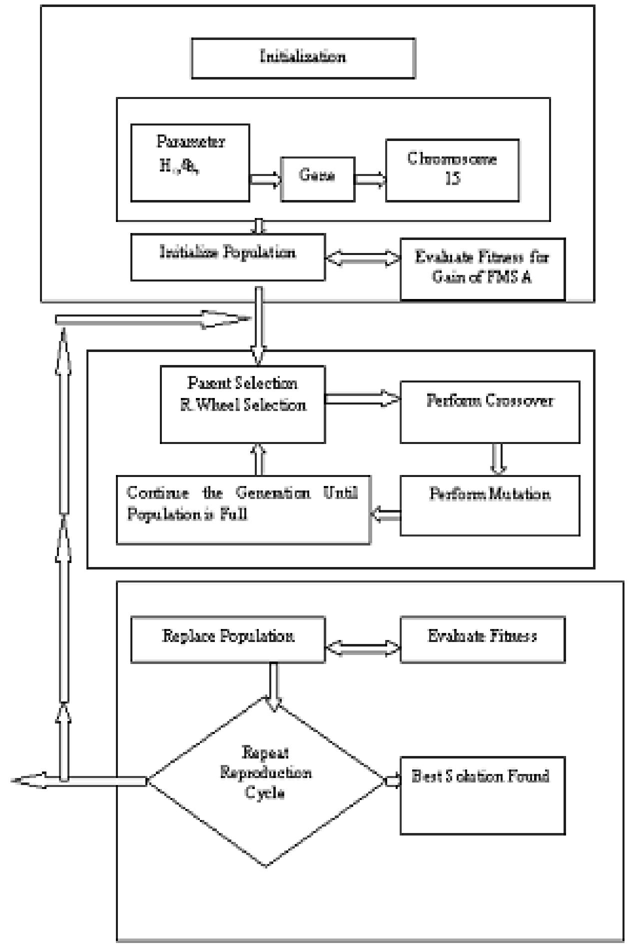

Fig.2 Flow Chart for the Optimization of Magnetized Ferrite Microstrip Antenna using Genetic Algorithm

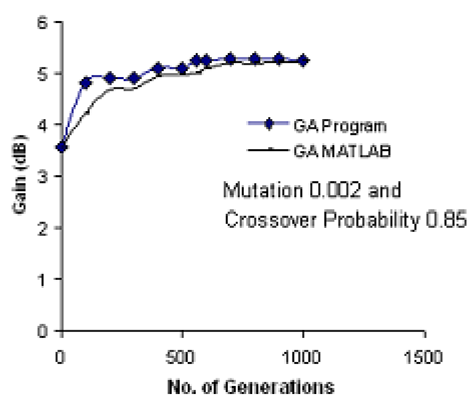

Fig.3 Variation of Gain of a Magnetized Circular FMSA with Number of Generation (for Magnetized Ferrite Material having Constant Saturation Magnetization)

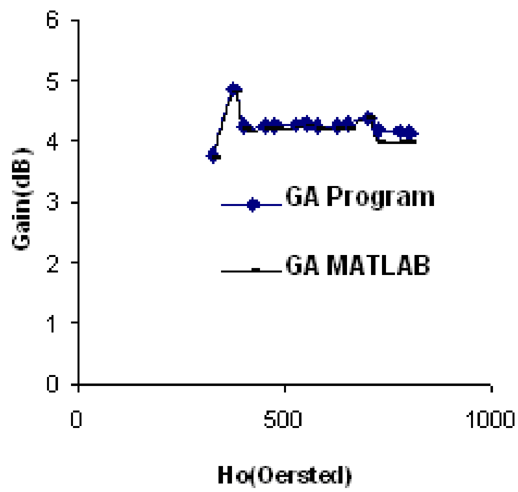

Fig.4 Variation of Gain of a Magnetized FMSA with Bias Magnetic Field (for Magnetize Ferrite Material having Constant Saturation Magnetization)

V. CONCLUSION

The method of application of Genetic Algorithm to the optimization of magnetized FMSA is described here. The gain of a ferrite microstrip antenna is a sensitive function of bias magnetic field and saturation magnetization of ferrite. A Genetic Algorithm code for magnetized ferrite microstrip antenna, is developed using C++ language where fitness function is obtained using cavity model for magnetized circular FMSA. The different parameters being varied are steady bias magnetic field, saturation magnetization, dielectric constant and height of the ferrite substrate. The optimized results are compared with the results obtained using GA optimizer of MATLAB.

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