Application of Genetic Algorithm to the Optimization of Microstrip Antennas with and without Superstrate

Neela Chattoraj, Jibendu Sekhar Roy

Abstract: **The application of Genetic Algorithm (GA) to the optimization of gain of microstrip antennas with and without dielectric superstrate is reported. In both the cases the fitness functions are developed using cavity method for the analysis of microstrip antenna. The results are supported by experimental verification.**

Keywords: **Genetic Algorithm, Microstrip antenna, Gain, Cavity method, Superstrate**

I. INTRODUCTION

A microstrip antenna is a metallic radiating patch fabricated over a dielectric substrate backed by a metallic ground plane and generally used in microwave and millimeter-wave frequencies. Microstrip antennas have found widespread applications for microwave and millimeter wave systems. In the design and syntheses of antennas, the goal is to find a radiating structure that meets performance criteria that may be gain, input impedance, beam width or a combination of any of the above parameters [1]. Microstrip antennas have been employed in airborne and spacecraft systems because of their low profile and conformal nature. Many of these applications require a dielectric cover over the radiating element to provide protection against heat, physical damage, and the environment. When a microstrip antenna is covered with a dielectric layer (superstrate), its properties like resonance frequency, gain are changed which may seriously degrade the system performance [1-7]. Therefore, in order to introduce appropriate correctness in the design of the antenna, it is important to determine the effect of dielectric layer on these antenna parameters.

This paper describes the use of Genetic Algorithm to optimize the gain of a rectangular microstrip antenna. The method is also extended to optimize the gain of a rectangular microstrip antenna covered with a dielectric layer. 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 [8] and this method can handle the common characteristics of electromagnetics [9]. The rectangular microstrip antenna was modeled using the cavity method of analysis and the fitness functions to optimize the gain and resonance frequency were obtained. The Genetic Algorithm program, for the optimization of microstrip antennas, is developed using C++ language. In both the cases, antenna was assumed to be operating in the fundamental TM_{10} mode. Optimization of gain, using GA, was done for many values of dielectric constant and substrate height. But to compare optimized maximum gains of rectangular microstrip antennas with measured results, only those values of dielectric constant and substrate height are chosen which are available with us. The optimized results are confirmed by measurement. The variations of resonance frequency and gain of a rectangular microstrip antenna covered with a dielectric layer were observed. The change of effective dielectric constant with the thickness of superstrate is more.

II. GENETIC ALGORITHM

Genetic Algorithm (GA) is a robust stockastic based search method that can handle the common characteristics of electromagnetics which can not be handled by other optimization techniques. Genes are the basic building blocks of a genetic algorithm. A gene is a binary encoding of a parameter. 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. 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. 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

Modeling the rectangular microstrip patch configuration (shown in fig.1) as a cavity, bounded at its top and bottom by electric walls and on its sides by a magnetic wall, the z-directed electric field inside the cavity can be written as,

$$E_z = E_o Cos \frac{m\pi x}{a} Cos \frac{n\pi y}{b} \tag{1}$$

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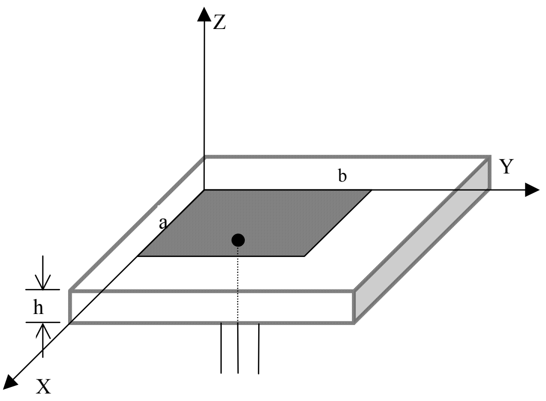

Fig. 1 Geometry of Microstrip Antenna

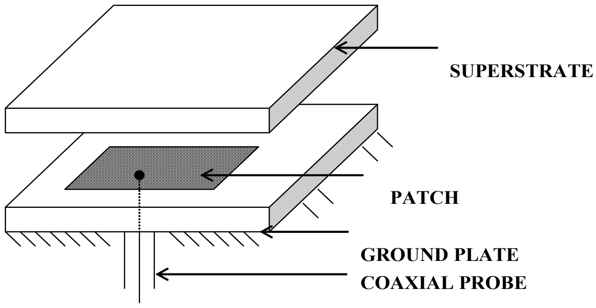

Fig. 2 Microstrip Antenna Covered with a Superstrate

Where *a* and *b* are the dimensions of the patch along *x* and *y* axes respectively. The dielectric constant and substrate thickness of the microstrip substrate are ε_r and *h* respectively. The magnetic wall boundary conditions are that the variation of *z*-directed electric field along *x* and *y* axes inside the cavity (figure-1) on the magnetic wall are equal to zero. Mathematically, these boundary conditions are expressed as $\delta Ez/\delta x = 0$ at y=0, b and $\delta Ez/\delta y = 0$ at x=0, *a*. The resonance frequency can be computed from the generalized formula. Considering slot-width around the patch is approximately equal to the substrate thickness, the resonance frequencies for TM_{10} and TM_{01} modes can be written as

$$f_{r10} = \frac{c}{2\sqrt{\varepsilon_e(b)}} \frac{1}{a+h} \tag{2}$$

$$f_{r01} = \frac{c}{2\sqrt{\varepsilon_e(a)}} \frac{1}{b+h} \tag{3}$$

The expressions for effective dielectric constants with superstrate, $\varepsilon_e(a)$ and $\varepsilon_e(b)$ can be found in [1]. 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. Far field components of a rectangular microstrip antenna may be calculated considering the radiator as a set of four slots of equal width. Then simplifying the expressions for far field components for (1, 0) mode, the expression for directivity of the antenna reduces to [10]

$$D = \frac{2h^2 E_o^2 b'^2 K_o^2}{P_r \pi \eta_o} \tag{4}$$

where $K_0 = 2\pi/\lambda_0$ (λ_0 is the free-space wavelength).

The efficiency of the antenna is

$$\eta = \frac{P_r}{P_T} \tag{5}$$

where, P_r is the radiated power, $b' = b + h$ and $\eta o = 120\ \pi\Omega$ is the free-space impedance. The expression for gain in (1, 0) mode becomes

$$G = \frac{P_r}{P_T} D = \frac{2h^2 E_o^2 b'^2 K_o^2}{P_T \pi \eta_o} \tag{6}$$

where, P_T is the total power loss of the antenna which includes dielectric, conductor and radiation losses. The expression for gain, obtained using cavity method and given by eqn.(6), is used for the fitness function which is mentioned in section IV. The expressions for effective dielectric permittivity for a microstrip antenna covered with a dielectric layer (fig. 2) and length extension are taken from literature [5]. In this case, effective dielectric permittivity depends on thickness and dielectric constant of the superstrate.

IV. METHOD OF APPLICATION OF GA TO THE MICROSTRIPANTENNAS AND COMPUTED RESULTS

The rectangular microstrip antenna is assumed to be operating at TM_{10} mode. All the parameters, that is, the length, width, thickness of the dielectric substrate and the value of the dielectric constant were coded into 8 bit scaled binary coding. Hence the total length of the chromosome was 32 bits. The genetic algorithm was ran for 30 to 80 generations. However after 70 generations the convergence is very slow. The number of genes per generation was varied from 40 to 100. However 40 to 60 genes per generation was found to be optimal for our application. The probability of crossover was varied from 0.3 to 0.8 and the probability of mutation was varied from 0.01 to 0.04. The range of the length *a* and width *b* were from 10 mm to 60 cm. The range of dielectric constant was kept from 2.2 to 4.8. The fitness function used for an antenna *x* is $f(x) = 10G(x) - f(res) - f(req)$, where $f(res)$, $f(req)$ and $G(x)$ are the resonance frequency of the antenna *x*, frequency at which the antenna is being optimized and gain of the antenna *x* as determined using cavity model analysis at TM_{10} mode respectively. The flow chart, describing the application of GA to the optimization of microstrip antenna is shown in fig. 3. The variation of gain of a rectangular microstrip antenna with number of generation for different values of mutation, obtained using GA, is shown in fig.4. In fig. 4, the gain is optimized at a frequency of 8 GHz. Both the length and width of the patch antenna were varied from 10 mm to 60 mm. The dielectric constant and height of the substrate were varied from 2 to 2.55 and 1 mm to 3 mm respectively. The maximum gain of 6.29 dB (at 77 generations) was obtained when length and width of the antenna was 13.10 mm and 10.25 mm respectively. The dielectric constant and height of the substrate at this

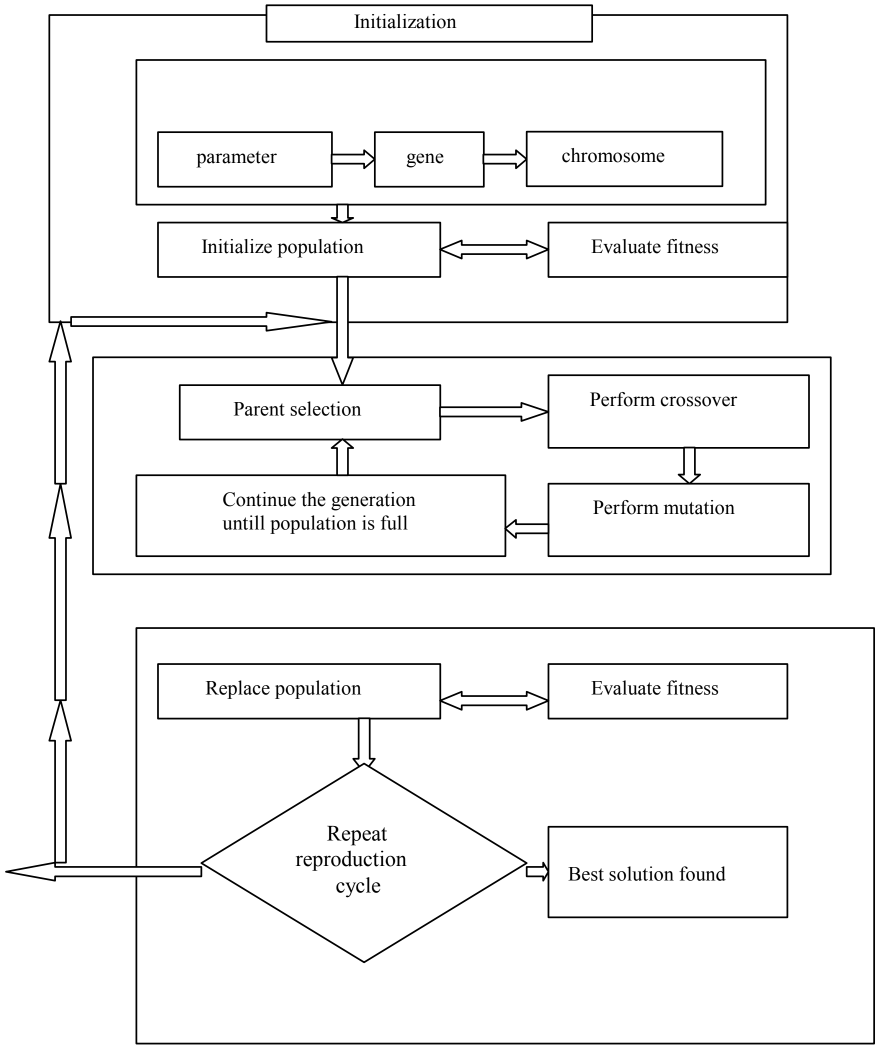

Fig.3 Flow Chart for the optimization of microstrip antenna using GA

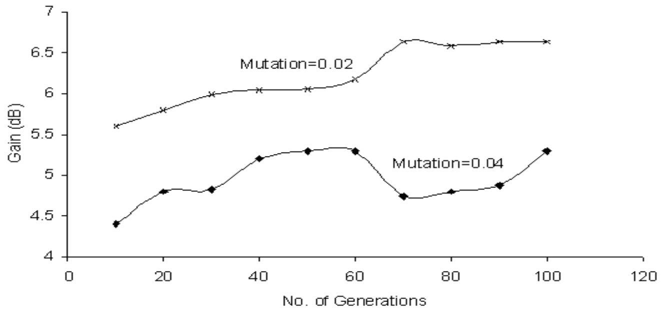

Fig. 4 Variation of Gain of a rectangular Microstrip Antenna (without dielectric cover) with number of generations for different mutation (at 8 GHz)

maximum gain was 2.55 and 1.57 mm. The GA optimization method is tested for different values of mutation. In figure-4, to show the effect of mutation on optimized gain, the results for mutation=0.02 and mutation=0.04 are plotted.

In the case of a microstrip antenna with a superstrate, the properties like radiation pattern, gain, effective dielectric constant, resonance frequency etc. change. But the change of effective dielectric constant is more and depends on thickness and dielectric constant of the superstrate [1,2,5]. Thus, to obtain the characteristics of microstrip antenna with cover layer, two extra parameters (in addition to length and width of the patch and substrate thickness), dielectric constant of the superstrate and superstrate thickness, are taken as input parameters in the GA optimization. The computed results for resonance frequencies and gains for rectangular microstrip antennas with dielectric cover layer, are plotted fig.5 and fig.6 respectively. The results agree with those reported in [1]. For both the figures, the values of the parameters were a=29.21mm, b=59.41mm, h=2.492mm, dielectric constant of ice is 3.05, dielectric constant of superstrate is 79. In both the cases the dielectric constant of the substrate was 2.55. It is found that the resonance frequency is decreasing on increasing the thickness of the substrate. The gain, in the case of ice layer on the patch, was found to increase monotonically for the thickness of the layer up to 100 mm. In the case of microstrip antenna covered with a superstrate of dielectric constant of 79, an increase in the gain was observed up to the thickness of 4 mm, after which the gain falls off. Therefore, there is an optimum thickness of the dielectric cover layer for obtaining the maximum gain.

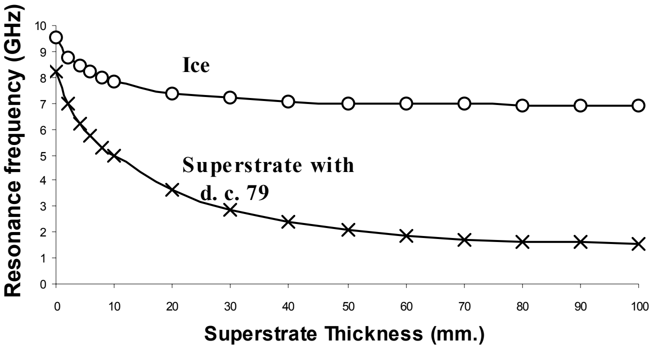

Fig.5 Variation of Resonant Frequency of Microstrip Antenna with Superstrate Thickness

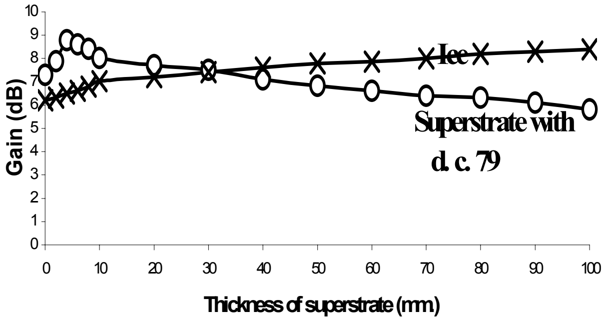

Fig.6 Variation of Gain of Microstrip Antenna with Superstrate Thickness

V. MEASURED RESULTS

Optimization of gain, using GA, was done for various values of dielectric constant and substrate height. But to compare optimized maximum gains of rectangular microstrip antennas with measured results, only those values of dielectric constant and substrate height are chosen which are available with us. The optimized results compared with measurement in Table I. The microstrip antennas, without any cover layer, were fabricated on PTFE substrate ($\varepsilon_r = 2.55$, $h = 3\text{mm}$) and Glass Epoxy substrate ($\varepsilon_r = 4.36$, $h = 1.57\text{mm}$) from Microline India, Calcutta and fed by SMA connectors at the 50 Ohm positions (obtained using Cavity model analysis). The dimensions of the rectangular microstrip antennas at 8 GHz and 9 GHz were 11.5 mm x 10 mm and 9.5 mm x 9 mm respectively. The measurements of gain of microstrip antennas, without superstrate, were done using X-band Microwave Test Bench (consisting of Micrometer, Gunn Oscillator, PIN modulator, Isolator, Variable Attenuator and Direct Reading absorption type Frequency Meter), Gunn Power supply, standard pyramidal Horn antenna (of gain 17dB) and HP Power meter. The resonant frequency of the antennas were measured using vector network analyzer. The small differences between computed and measured gains are due the fact that measurements were not performed in anechoic chamber and due to power loss in the co-axial feed line, which has not taken into account in the theory.

TABLE I: COMPARISON BETWEEN COMPUTED AND MEASURED RESULTS

	Reso. Frequency	Gain
PTFE ($\varepsilon_r = 2.55$, $h = 3\text{mm}$)		
Computed Result	8.00 GHz	6.02 dB
Measured Result	8.08 GHz	5.75 dB
Glass Epoxy ($\varepsilon_r = 4.36$, $h = 1.57\text{mm}$)		
Computed Result	9.00 GHz	6.35 dB
Measured Result	9.10 GHz	5.80 dB

VI. CONCLUSION

The method of application of Genetic Algorithm to the optimization of microstrip antennas with and without dielectric cover, is described here. Some of the results are verified by measurement. A GA code for microstrip antenna, is developed using C++ language. The results agree well with measured results and the computed results for microstrip antennas with two types of dielectric superstrates agree with the previous reports.

REFERENCES

[1] R. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, Microstrip Antenna Design Handbook, Artech House, 2001.

[2] I. J. Bahl, P. Bhartia and S. S. Stuchly, “ Design of a Microstrip Antenna Covered with a Dielectric Layer”, IEEE Trans. Antennas & Propagation, Vol. AP-30, pp. 314-318, March 1980.

[3] N. G. Alexopoulos and D. R. Jackson, “Fundamental Superstrate (Cover) Effect on Printed Circuit Antennas”, IEEE Trans. On Antennas & Propagation, Vol. AP-32, pp. 807-816, 1984.

[4] H-Y. Yang and N. G. Alexopoulos, “Gain Enhancement Methods for Printed Circuit Antennas Through Multiple Superstrates”, IEEE Trans. Antennas & Propagations, Vol. AP-35, pp. 860-863, 1987.

[5] C-Y. Huang, “Gain-Enhanced Compact Broadband Microstrip Antenna”, Electron. Letter, Vol.34, pp. 138-139, 1998.

[6] D. Guha and J. Y. Siddiqui, “Resonant Frequency of Circular Microatrip Antenna Covered with Dielectric Superstrate”, IEEE Tans. Antennas & Propagation, Vol. 51, No. 7, pp. 1649-1652, July 2003.

[7] F. J. Villegas, T. Cwik, Y. Rahamat-Samii and M. Manteghi, “A Parallel Electromagnetic Genetic-Algorithm Optimization (EGO) Application for Patch Antenna Design”, IEEE Trans. Antennas & Propaga-tions, Vol. AP-52, No. 9, pp. 2424-2435, 2004.

[8] D. E. Goldberg, Genetic Algorithms, Addison-Wesley, 1989.

[9] R. L. Haupt, “An Introduction to Genetic Algorithms for Electromagnetics:, IEEE Antennas & Propagation Magazine, Vol. 37, No. 2, pp. 7-15, 1995.

[10] J. S. Roy, “Some Investigations on Microstrip Antennas”, Post-Doctoral Report, University of Limoges, France, 1993