Bandwidth Enhancement in Patch Antenna by Optimizing Patch Geometry using Genetic Algorithm

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Abstract- **Antenna design has grown more stringent and difficult over the years as the world becomes strictly a wireless environment. In order to overcome the limitations of microstrip antennas such as narrow bandwidth, lower gain, excitation of surface waves etc, Genetic Algorithm (GA) is being successfully applied by a number of researchers to improve the impedance bandwidth. The aim of this project is to design, simulate and fabricate the GA optimized Microstrip patch Antenna (MSA) operating at 2.5GHz frequency and study the performance of the rectangular microstrip antenna (RMSA) comparing to an unoptimized RMSA.**

Keywords**— Microstrip Antenna, Genetic Algorithm, Bandwidth, Optimization, VSWR.**

I. Introduction

A microstrip antenna (MSA) consists of a conducting patch of any planner or non-planner geometry on one side of a dielectric substrate with a ground plane on the other side. In spite of their various attractive figures like low profile, light weights, low cost, easy fabrication and so on, the microstrip elements suffer from an inherent limitation of narrow impedance bandwidth and low gain in the order of 6dB [1]. So, widening the bandwidth of microstrip elements has become a major branch of activities in this field. In recent years, the use of evolutionary algorithms to optimize antenna designs has shown tremendous growth. Genetic algorithms (GA) [2] are global optimization techniques that are based on the Darwinian theory of natural selection and evolution. Genetic algorithms offer many advantages over traditional numerical optimization techniques including the ability to use both continuous and discrete parameters, search across a wide sampling of the solution space, and handle a large number of variables.

II. Genetic Algorithm

Holland first introduced GA's in 1975 [2], but they were not applied to practical problems till Goldberg in the late 80s and early 90s [2]. In the 90s, GA's used within electromagnetics have been most often applied to antenna array design for array thinning, beamforming, and sidelobe minimization [2]. In the past few years, the use of genetic algorithms have spread to the design of single antennas in order to optimize parameters such as size, bandwidth, efficiency, radiation pattern, and gain [2]. A genetic algorithm (GA) offers an alternative to traditional local search algorithms. It is an optimization algorithm inspired by the well-known biological processes of genetics and evolution. A combination of genetics and evolution is analogous to numerical optimization in that they both seek to find a good result within constraints on the variables. Input to an objective function is a chromosome. The output of the objective function is known as the cost when minimizing. Each chromosome consists of genes or individual variables. The genes take on certain alleles much as the variable has certain values. A group of chromosomes is known as a population. For our purposes, the population is a matrix with each row corresponding to a chromosome: It is the cost that determines the fitness of an individual in the population. A low cost implies a high fitness.

A basic GA is quite simple and powerful. The algorithm has the following steps:

1. Create an initial population.
2. Evaluate the fitness of each population member.
3. Invoke natural selection.
4. Select population members for mating.
5. Generate offspring.
6. Mutate selected members of the population.
7. Terminate run or go to step 2.

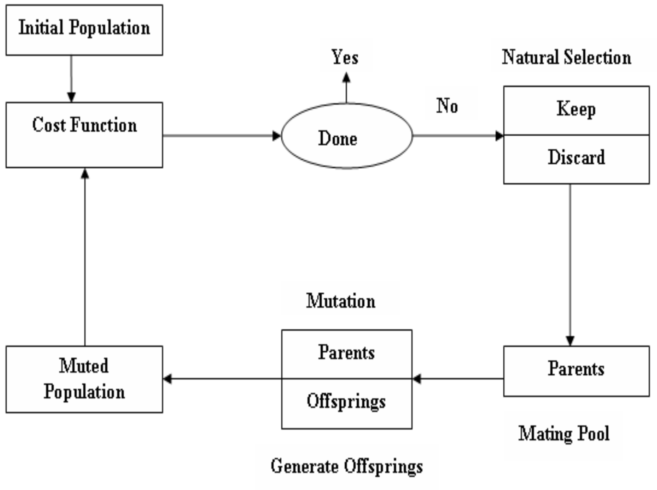

Fig. 1 Flow chart of Genetic Algorithm

III. GENETIC ALGORITHM (GA) AND MICROSTRIP PATCH ANTENNA (MSA)

The use of genetic algorithms in optimizing microstrip patch antennas is relatively recent, with the majority of research occurring in the past few years. The objective is to create novel, non-intuitive shapes that fulfill the optimization criteria, such as a broad bandwidth, dual frequency, or small physical dimension. A genetic algorithm was used to determine the patch length and width and feeding point in the design of a coaxially fed circularly polarized rectangular patch antenna. The fitness function was derived from the cavity model and evaluated such antenna characteristics as input impedance, effective loss tangent, and axial ratio. A stacked patch antenna that exhibited broadband operation was designed using a GA. The GA controlled numerous variables including the size of each patch, the thickness and permittivity of each dielectric slab, and the feed location.

IV. PARAMETRIC STUDY OF MSA AT 2.5GHZ FREQUENCY

For the fundamental TM_{10} mode, we apply 2.5 GHz as resonant frequency to design an RMSA. So, the wavelength of the resonant frequency is 0.12 m or 12 cm. The BW of the MSA is directly inversely proportional to the square root of its dielectric constant ε_r. As a result, a thicker substrate with a low dielectric constant is generally used to obtain broad BW. We select Rogers RT/duroid 5800 substrate with relative permittivity 2.2 and very low dielectric loss, $\tan\delta$ with 0.001.

TABLE I

UNOPTIMIZED MSA CONFIGURATION

Parameter	Value
Height, h	0.38cm
Width, W	4.5cm
Length, L	4cm
Relative Permittivity, Rogers RT/duroid 5800	2.2
Feedpoint*	-0.6cm from center of Length
Feed radius*	0.07cm

* The values of feedpoint and feed radius has been taken from the parametric study of RMSA of “Compact and Broadband Microstrip Antenna” by Girish Kumar and K.P. Ray.

V. MSA DESIGN IN HFSS

Designing a patch to resonant at a particular frequency involves only a few steps when using a simulation tool, such as Ansoft High Frequency System Simulator (HFSS). The four main design parameters for a microstrip patch antenna are the width and length of the patch, and the height and permittivity of the dielectric. Here, in HFSS modeling 2.5 GHz resonance is examined. The substrate dimensions are 6 cm by 7 cm, with the thickness of 0.38 cm, a permittivity 2.2 and a loss tangent 0.001. In the figure 2 and 3, the substrate is based on the infinite ground plane on 6cm x 7cm platform. The patch dimensions are 4cm x 4.5cm and an air-box surrounding the antenna providing a radiation boundary is 6cm x 7cm x 3cm. The patch is fed by a lumped port of 0.07cm radius and centered at 0.6cm right away from the central x-axis of the patch with an impedance of 50 Ω.

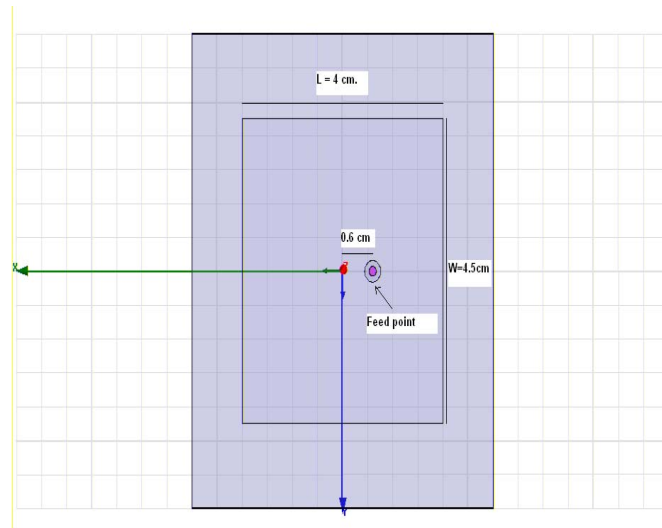

Fig. 2 Top View of Unoptimized MSA

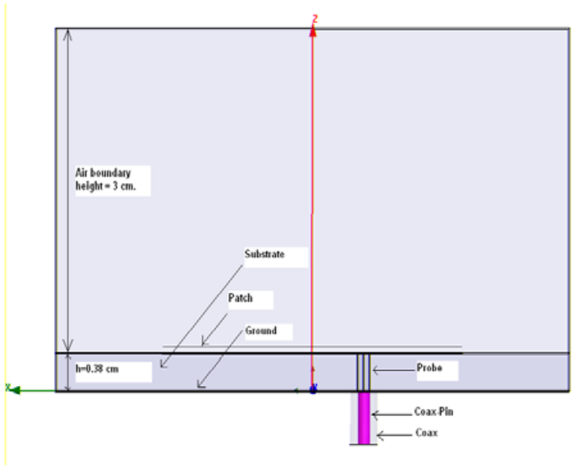

Fig. 3 Side View of Unoptimized MSA

VI. Result Analysis of Unoptimized MSA

The S_{11} is plotted on the Smith Chart in figure 4, and the

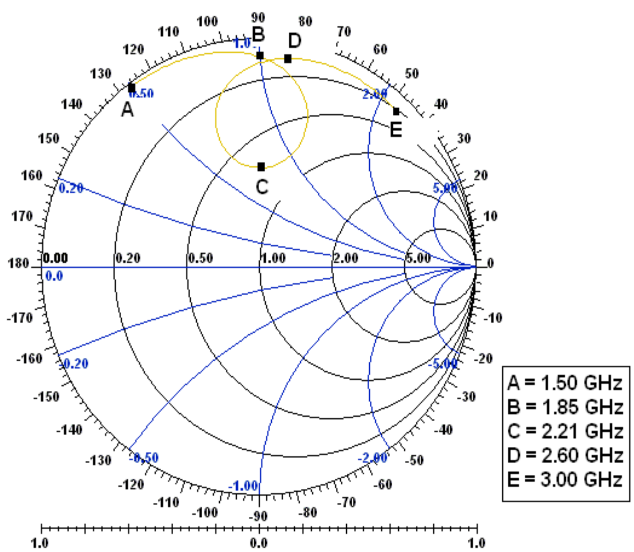

Fig. 4 Smith Chart of Unoptimized MSA

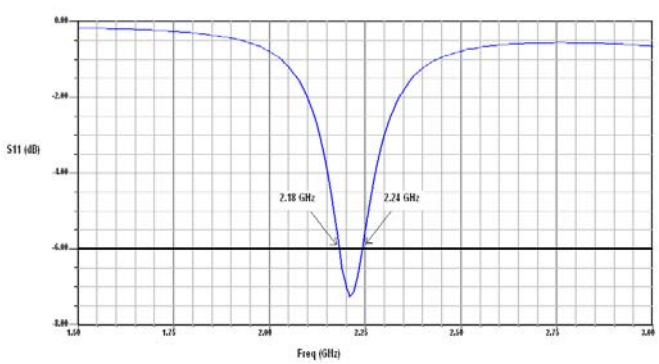

Fig. 5 S_{11} – Freq Graph of Unoptimized MSA

frequency where the impedance becomes purely resistive is the resonant frequency of the patch. Figure 4 shows the VSWR is 2.55 and the Q factor is 1.078. The impedance of the antenna is 0.678+j0.741. From frequency sweep, in figure 5, plotting the S_{11} versus frequency reveals the 2.21 GHz resonance at a return loss of -7.25dB. If we consider the return loss of -6dB we get 60MHz bandwidth from the patch antenna design.

VII. GA Parameter Input in SuperNEC 2.9

To optimize the previously calculated geometry of the patch antenna, we consider its substrate height, patch width and patch length. For this we use the GUI of the SuperNEC simulator. In Solver section, both patch length and width are initialized -1 and are bounded by minimum value 25mm and maximum 50mm with the resolution of 1mm x 1mm. The substrate height is also initialized -1 and is bounded by minimum value 3mm and maximum value 4mm. But the resolution is set here 0.1mm x 0.1mm. Feedposition is taken into axis co-ordinate system of [0.006m, 0.0001 ≈ 0m(as SuperNEC doesn't allow 0 input in this case)]

TABLE II

Basic Parameters' Boundary Values of MSA for GA Optimization

Parameter	**Min**	**Max**
Height, h	0.3 cm	0.4 cm
Width, W	2.5 cm	5.0 cm
Length, L	2.5 cm	5.0 cm

The built in fitness function used by the optimiser is as follows:

$$Fitness \;/\; Cost \;=\; \left(\frac{ActualGain}{\mathrm{Re}\; q.Gain}\right)^{gFactor} + \left(\frac{\mathrm{Re}\; q.VSWR}{ActualVSWR}\right)^{vFactor}$$

In SuperNEC, cost/fitness settings, we select 10dB gain as Required Gain and gain factor (gFactor) of 2 and required VSWR is 1 and VSWR factor (vFactor) of 2. The cost calculation adopts 'Average cost' method for the output. In Genetic Algorithm setting section, for the selection of fittest population, we take 'Tournament Selection' and for mate we select 'Emperor Selection'. For generating offspring, we select 'Random Crssover Points' with a mutation rate of 0.25 (i.e.25%). In model settings, simulation frequency is 2500MHz (2.5GHz) with line impedance 50 Ω.The Genetic Algorithm will run upto 10 generation creating 10 chromosomes in each generation and finally select the best fit chromosome from that. As we use infinite ground plane in the previously simulated RMSA, we select 'NONE' ground as SuperNEC provide no infinite groundplane. Ofcourse, this is not vulnerable part cause we will verify the output of the SuperNEC's optimization by HFSS simulator.

VIII. GA Optimized MSA Configuration

TABLE III

GA OPTIMIZED MSA CONFIGURATION

Parameter	Value
Height, h	0.35cm
Width, W	3.5cm
Length, L	3.5cm
Relative Permittivity, Rogers RT/duroid 5800	2.2
Feedpoint*	-0.6cm from center of Length
Feed radius*	0.07cm

* The values of feedpoint and feed radius has been taken from the parametric study of RMSA of "Compact and Broadband Microstrip Antenna" by Girish Kumar and K.P. Ray.

IX. RESULT ANALYSIS OF GA-OPTIMIZED MSA

The S_{11} is plotted on the Smith Chart in figure 6, and the frequency where the impedance becomes purely resistive is

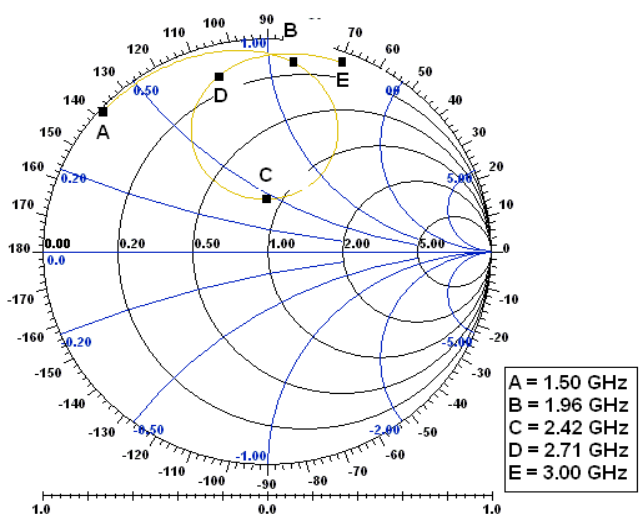

Fig. 6 Smith Chart of GA optimized MSA

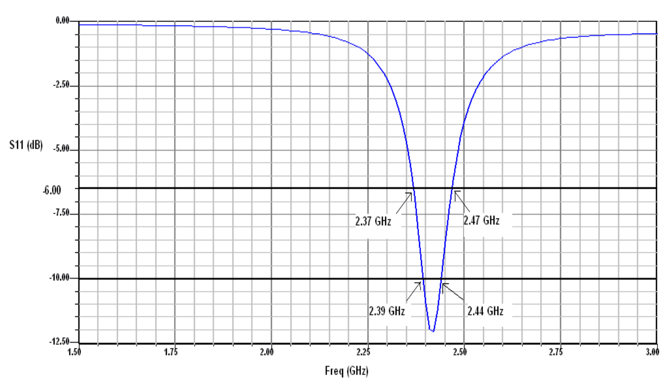

Fig. 7 S_{11} -Freq graph of GA optimized MSA

the resonant frequency of the patch. Figure 6 shows the VSWR is 1.678 and the Q factor is 0.538. The impedance of the antenna is 0.836+j0.45. From frequency sweep in the figure 7, plotting the S_{11} versus frequency reveals the 2.42 GHz resonance at a return loss of -12.10dB. If we consider the return loss of -6dB, we get 100MHz bandwidth and if we consider the return loss of -10dB, we get 50MHz bandwidth from the patch antenna design.

X. RESULT COMPARISON BETWEEN GA-OPTIMIZED AND UNOPTIMIZED MSA

From the Table III, it is clearly shown that in GA-optimized MSA BW enhancement occured at S_{11}<-6dB is 66.66%. At S_{11}<-20dB the GA-optimized MSA has 50 MHz while the unoptimized MSA doesn't have that at all. Patch Reduced after optimization is 30.55% while gain and directivity enhancement is 13.64% and 8.93% respectively. As well as Q factor lowering after optimization is 50.1%. In GA-optimized MSA, VSWR is 1.678 which is the sign of well impedance matching of the feed and antenna.

TABLE IV

OUTPUT COMPARISON OF GA OPTIMIZED RMSA AND UNOPTIMIZED RMSA

	Unoptimized at 2.21 GHz	**GA optimized at 2.42 GHz**
BW, S11<-6dB	(2.24-2.18) GHz = 60 MHz	(2.47-2.37)GHz = 100 MHz
BW, S11<-10dB	N/A	(2.44-2.37) GHz = 50 MHz
Directivity	16.8 dBi	18 dBi
Gain	16.5 dBi	18.2 dBi
Q factor	1.078	0.538
VSWR	2.55	1.678
RX (Normalized)	0.687 + j 0.741	0.836 + j 0.45
GB (Normalized)	0.673 – j 0.726	0.928 – j 0.5

ACKNOWLEDGMENT

This paper is written from my M.Sc. research on bandwidth enhancement techniques in MSA where my supervisor Professor Dr.Md. Ruhul Amin has immense contribution. The simulation and the results are analyzed in HFSS simulator of Ansoft corporation and optimization is done by SuperNEC simulator which is linked to MATLAB of Mathwork Inc.

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