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Analysis and Simulation of H-Shape Microstrip Patch Antenna using an Adaptive FDTD Method

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Abstract – **In this paper, the characteristics of a small antenna using an H-shaped microstrip patch are studied. Significant reduction in antenna size can be realized when the H-shaped patch is used instead of the conventional rectangular microstrip patch antenna. The theoretical analysis will carried out based on the finite-difference time-domain (FDTD) method, optimization of output of this microstrip patch antenna will done using Genetic algorithm scheme, in order to find best results. The FDTD programs can be develop and validate by available measurement results. The effects of various parameters of antenna on the resonant frequency and radiation patterns will use to carry results. Several design curves should be use, which are useful for practical antenna design. The current distributions on the patch and those on the ground plane are described together with the results illustrating the electric field distributions under the patch. This antenna is appropriate for applications where small size and broad beam-width are required.**

Keywords – **Microstrip Patch Antenna, FDTD, Genetic Algorithm Scheme.**

I. Introduction

Microstrip patch antennas are enjoying increasing popularity for their use in wireless applications due to their low-profile structure. Therefore these are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The communication and telemetry antennas on missiles need to be thin and conformal and are often in the form of microstrip patch antennas. However, a major drawback of these antennas is the low bandwidth. Several methods exist for the analysis of microstrip antennas. They can be classified as the Transmission Line Model (TLM), cavity model and full wave models. Finite Element Method (FEM), FDTD, Integral Equation – Method of Moment (IE – MoM) are some of the prominent full wave models. The stacked microstrip antenna has been analysed numerically by using the spectral domain method [2–5]. In these papers, the impedance characteristics of the stacked microstrip antenna is mainly discussed. It has been experimentally shown that the stacked microstrip antenna has a high gain when the distance between the fed patch and parasitic patch is 0.3 to 0.5λ [1, 6, and 7]. However, there is no paper what explains relations between the gain enhancement and near field distributions of the stacked microstrip antenna.

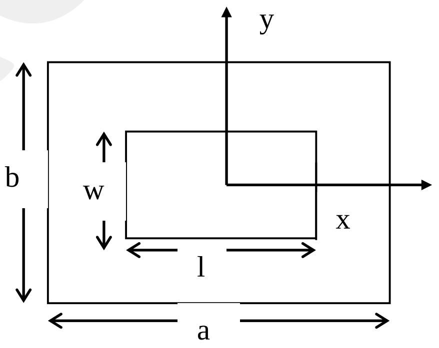

Figure 1: Geometry of Rectangle shaped Microstrip Antenna with Rectangular Slot

Finite-difference time-domain (FDTD) is a numerical analysis technique used for modeling computational electrodynamics (finding approximate solutions to the associated system of differential equations). Since this is a time-domain method, FDTD solutions cover a wide frequency range with a single simulation run, and can treat nonlinear material properties in a natural way. Finite-difference time-domain (FDTD) is a numerical analysis technique used for modeling computational electrodynamics (finding approximate solutions to the associated system of differential equations). The emphasis here is on the feed model and the calculation of radiation patterns. A Gaussian pulse with unit amplitude, provided by

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$$V(t) = e^{-\frac{(t-t_0)^2}{T^2}} \quad (1)$$

is excited in the probe feed. The dimensions of the FDTD unit cell, Δx, Δy, Δz, are chosen such that integral number of nodes can fit exactly all the dimensions of the patch antenna. To accurately model the spatial variation of field in the slot, the unit cell dimensions are also constrained to a fraction of the slot length and width under consideration. This defines the antenna parameters taken into consideration. The first segment of paper throws light on the general theory of micro-strip antennas and the finite difference time domain. The segment illustrates the dependency of micro-strip antenna over FDTD for parameter efficiency and its application where small size broad beam-width is required. The second segment is the study of various literatures associated with our work. A study of various papers helped to understand the past scenario of the development and gave us inspiration to define better outputs. Our proposed work is then formulated in next segment. The authenticity of work is witnessed by the results discussed further.

II. LITERATURE SURVEY

A broadband E-shaped micro-strip antenna is proposed in [8]. Its bandwidth is further increased by inserting a pair of tapered slits into an appropriate radiating edge of the rectangular patch antenna. The Antenna is designed and then simulated by three-dimensional electromagnetic field software HFSS. Results of paper shows that the designed antenna has an impedance bandwidth over 21% (from 12.7GHz to15.7 GHz) for VSWR <; 2, which is four times greater than the conventional rectangular patch antenna. Satisfactory patterns of radiation have also been obtained through simulation. The maximum gain in frequency band is 8.52dB. The resulting size of the microstrip antenna is 15 mm×15mm, realizing miniaturization, high power gain, and wide band features of the microstrip antennas.

In [9], a four element and an eight element Microstrip array antenna with its printed feed network on a monolithic substrate is first analyzed for the predicted radiation patterns and compared with experimental results. The gain enhancement of the Microstrip array with dielectric lens is then studied. The advantage of using dielectric lens is observed to be 4dbi extra gain which translates to an effective larger size antenna. These types of array lens are useful as low cost smart antenna. The experiment is carried out in S band range of frequencies.

In [10], a new design technique for the impedance matching of inset feed section that improves the performance of a conventional and grooved microstrip patch antenna is proposed. The purposed impedance matching technique for inset feed microstrip patch antenna is based on the concept of coplanar waveguide feed line and has been investigated for a printed antenna at X-Band antenna operating at a frequency of 10GHz. The proposed technique has been used in the design of Grooved Microstrip patch antenna array.

In [11], a novel multi-slotted microstrip patch antenna with high gain is presented and discussed. The design adopts contemporary techniques such as probe feeding and multi-slotted patch. These techniques can contribute to the enhanced performance of the antenna. The design also employs a novel shape patch. By integrating these techniques the proposed design offers low profile, high gain and compact antenna element. The maximum gain at the resonant frequency of 2.45GHz is 11.35dBi. The lowest return loss can be -34.49 dB at 2.45GHz. The proposed design has a simple structure and a compact dimension of 87mm*51mm. The proposed design is suitable for particular wireless communication application such as WiFi and WLAN.

In [12], a small compact Microstrip patch antenna with C-shaped slot is presented and simulated using Advanced Design Systems. It is developed to operate in the WiMax frequency range of 2.5-2.69 GHz. The antenna presents a size reduction of about 37% when compared to a conventional patch antenna. The return loss is -19.1 dB and the antenna presents a broad radiation pattern.

The author in [13] focuses on overview of defected ground structure (DGS).The basic conceptions and transmission characteristics of DGS are introduced and the equivalent circuit models of varieties of DGS units are also presented. Finally, the main applications of DGS in microwave

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technology field are summarized and the evolution trend of DGS is given.

III. PROPOSED WORK

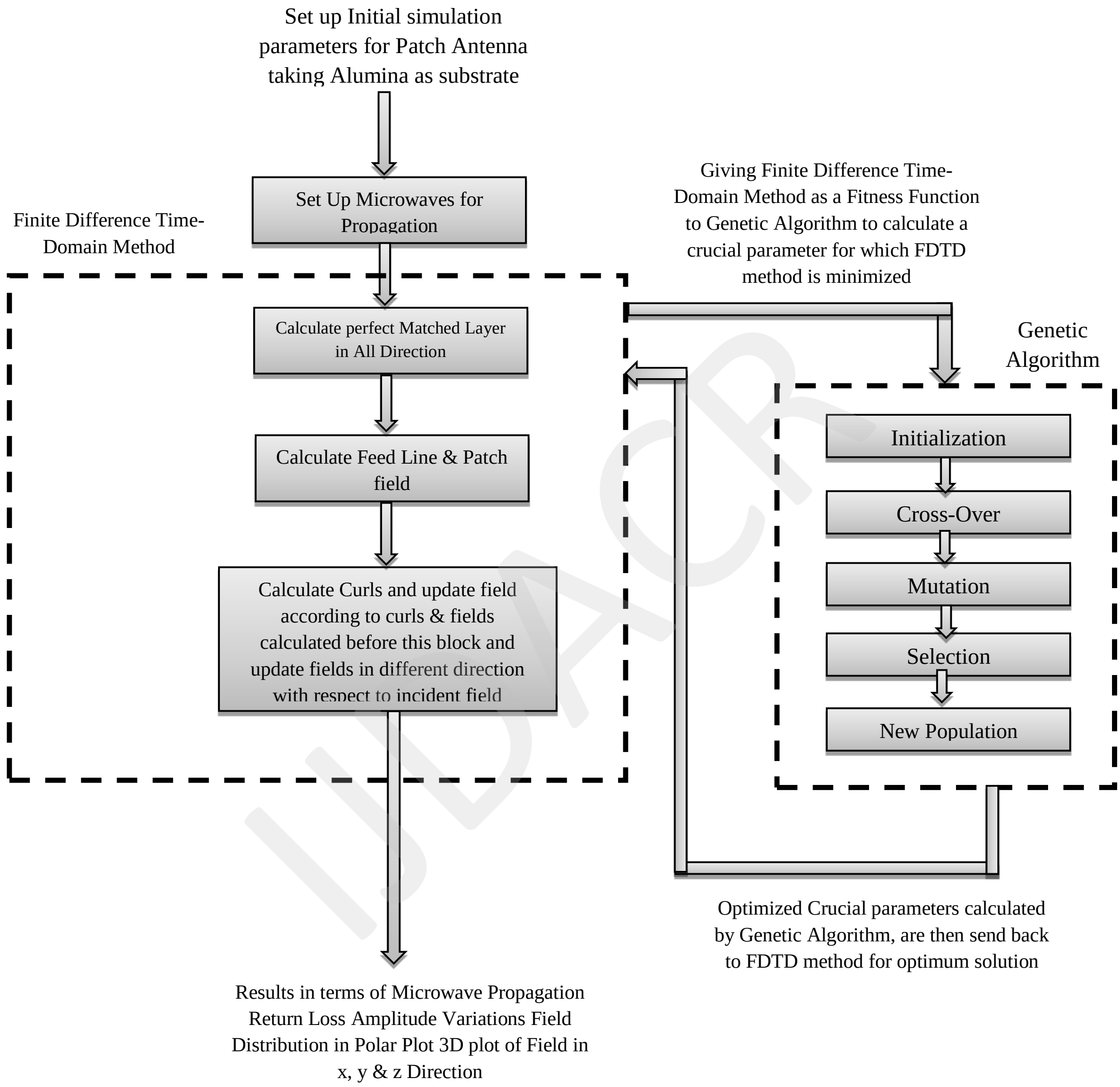

Figure 2: Flow of Proposed Work

In the theoretical analysis, we use the finite-difference time-domain (FDTD) algorithm, because it is very simple to understand and can be used to analyze antennas of many complex structures. As the detailed theory on FDTD is available in [14], [15], [16], [17], [18], only a brief outline will be presented here. The first step in designing an antenna with an FDTD code is to grid up the object. A number of parameters must be considered in order for the code to work successfully. The grid size must be small enough so that the fields are sampled sufficiently to ensure accuracy. Once the grid size is chosen, the time step is determined such that numerical instabilities can be avoided, according to the courant stability condition.

A Gaussian pulse voltage with unit amplitude is given by

$$V(t) = e^{-\frac{(t-t_0)^2}{T^2}} \qquad (2)$$

Where T denotes the period andt0 identifies the center time, is excited in the probe feed. For the feed

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probe, we use a series resistor R_s with the voltage generator to model the current in the feed probe. To truncate the infinite space, a combination of the Liao's third order absorbing boundary conditions (ABC) and the super-absorbing technique is applied, as in [15], [16], and [17]. After the final time-domain results are obtained, the voltage and current are transformed to those in the Fourier domain.

The input impedance of the antenna is then obtained from

$$Z_{in} = \frac{V(f)}{I(f)} - R_s \tag{3}$$

To get the electric current distributions on the patch and the ground plane, we have used a sinusoidal excitation at the probe feed, which is given by

$$V(t) = sin2\pi f_0 t \tag{4}$$

Where f_0= the resonant frequency of interest. The field distributions are recorded at one instant of time after the steady state has been reached. In our analysis, the overall time for stability is more than 6 cycles. The electric current distributions and j_y on the metals are obtained by the difference between the tangential magnetic fields above and below the metal interface. After the field distribution has been obtained, the radiation pattern can be readily calculated by using the near-field to far-field transformation.

Normalisation of Maxwell's equations

Here we are using the normalized general form of field variables for the simplicity of formulation.

$$\bar{E} = E/\eta \tag{5}$$

Where $\eta = \sqrt{\frac{\mu_0}{\varepsilon_0}}$

The normalised Maxwell's curl equations are:

$$\frac{\partial \bar{D}}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \nabla \times \bar{H} \tag{6}$$

$$\bar{D}(w) = \varepsilon_r^{\cdot}(w).\bar{E}(w) \tag{7}$$

$$\frac{\partial \bar{H}}{\partial t} = -\frac{1}{\sqrt{\varepsilon_0 \mu_0}} \nabla \times \bar{E} \tag{8}$$

Where E, H are the electric and magnetic field respectively and ε is permittivity, σ is conductivity and μ is permeability.

Normalisation is used for the field variables having the same order of magnitude. The above equations generate six scalar equations. All field variables *Dx, Dy, Dz* and *Hx, Hy, Hz* are normalized and we are eliminating dash symbol present in the field components of equation 6 and 8.

$$\frac{\partial Dx}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \left(\frac{\partial Hz}{\partial y} - \frac{\partial Hy}{\partial z} \right) \tag{9}$$

$$\frac{\partial Dy}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \left(\frac{\partial Hx}{\partial z} - \frac{\partial Hz}{\partial x} \right) \tag{10}$$

$$\frac{\partial Dz}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \left(\frac{\partial Hy}{\partial x} - \frac{\partial Hx}{\partial y} \right) \tag{11}$$

$$\frac{\partial Hx}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \left(\frac{\partial Ey}{\partial z} - \frac{\partial Ez}{\partial y} \right) \tag{12}$$

$$\frac{\partial Hy}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \left(\frac{\partial Ez}{\partial x} - \frac{\partial Ex}{\partial z} \right) \tag{13}$$

$$\frac{\partial Hz}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \left(\frac{\partial Ex}{\partial y} - \frac{\partial Ey}{\partial x} \right) \tag{14}$$

Discretizing the equations 11 and 14, i.e. for *Dz* and *Hz* is:

$$\begin{aligned} Dz^{\eta+\frac{1}{2}}_{i,j,k+\frac{1}{2}} = Dz^{\eta-\frac{1}{2}}_{i,j,k+\frac{1}{2}} &+ \frac{\Delta t}{\sqrt{\mu_0 \varepsilon_0}\Delta x} \Big\{ Hy^{\eta}_{i+\frac{1}{2},j,k+\frac{1}{2}} \\ &- Hy^{\eta}_{i-\frac{1}{2},j,k+\frac{1}{2}} - Hx^{\eta}_{i,j+\frac{1}{2},k+\frac{1}{2}} \\ &+ Hx^{\eta}_{i,j-\frac{1}{2},k+\frac{1}{2}} \Big\} \end{aligned} \tag{15}$$

$$\begin{aligned} Hz^{\eta+1}_{i+\frac{1}{2},j+\frac{1}{2},k} = Hz^{\eta}_{i+\frac{1}{2},j+\frac{1}{2},k} &- \frac{\Delta t}{\sqrt{\mu_0 \varepsilon_0}\Delta x} \Big\{ Ey^{\eta+1/2}_{i+1,j+\frac{1}{2},k} \\ &- Ey^{\eta+1/2}_{i,j+\frac{1}{2},k} - Ex^{\eta+1/2}_{i+1/2,j+1,k} \\ &+ Ex^{\eta+1/2}_{i+\frac{1}{2},j,k} \Big\} \end{aligned} \tag{16}$$

Similarly we can write all the other difference equation also.

From the above difference equation the code for all

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the six fields can be written as:

dx(i,j,k) = dx(i,j,k) + 0.5* (hz(i,j,k) - hz(i,j-1,k) - hy(i,j,k) + hy(i,j,k-1)); (17)

dy(i,j,k) = dy(i,j,k) + 0.5* (hx(i,j,k) - hz(i,j,k-1) - hz(i,j,k) + hz(i-1,j,k)); (18)

dz(i,j,k) = dz(i,j,k) + 0.5* (hy(i,j,k) - hy(i-l,j,k) - hx(i,j,k) + hy(i,j-1,k); (19)

ex(i,j,k) = gax(i,j,k) * dx(i,j,k); (20)

ey(i,j,k) = gay(i,j,k) * dy(i,j,k); (21)

ez(i,j,k) = gaz(i,j,k) * dz(i,j,k); (22)

Now the role of artificial intelligence come into existence. It is clear with the help of equations from (20) to (22), the electric field components (ex, ey and ez) are set through the genetically optimised components, gax, gay and gaz respectively. By taking FDTD method as fitness function for genetic algorithm, and giving a suitable values of upper bound and lower bounds. The genetic algorithm gives the optimum value for the electric field components and we give it to FDTD method.

hx(i,j,k) = hx(i,j,k) + 0.5* (ey(i,j,k+ 1) - ey(i,j,k) - ez(i,j+ 1,k) + ez(i,j,k); (23)

hy(i,j,k) = hy(i,j,k) + 0.5* (ez(i+1,j,k) - ez(i,j,k) - ex(i,j,k+1) + ex(i,j,k); (24)

hz(i,j,k) = hz(i,j,k) + 0.5* (ex(i,j+1,k) - ex(i,j,k) - ey(i+1,j,k) + ey(i,j,k); (25)

Since the term, $\frac{\Delta t}{\sqrt{\mu_0 \varepsilon_0}\Delta x} = 0.5$

Where, gax(i,j,k) = gay(i,j,k) = gaz(i,j,k) = $\frac{1}{\varepsilon_r + \frac{\sigma dt}{\varepsilon_0}}$ (26)

For free space its value is unity.

Genetic Algorithm

A genetic algorithm is a probabilistic search technique that computationally simulates the process of biological evolution. It mimics evolution in nature by frequently altering a population of candidate solutions until an optimal solution is found.

The GA evolutionary cycle starts with a randomly selected initial population. The changes to the population happen through the processes of selection based on fitness, and alteration using mutation and crossover. The application of selection and alteration leads to a population with a higher proportion of improved solutions. The evolutionary cycle carry on until an acceptable solution is found in the current generation of population, or some regulator parameter such as the number of generations is exceeded.

The Genetic algorithm procedure is discussed through the GA cycle:

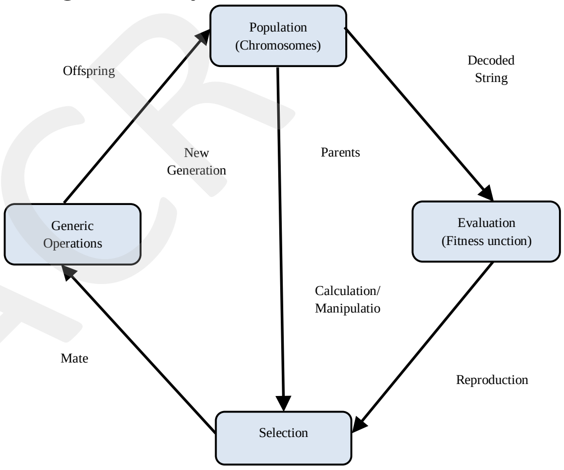

Figure 3: Genetic Algorithm Cycle

The basic genetic algorithm is as:

1. Start: Genetic random population of n chromosomes (suitable solutions for the problem).

2. Fitness: Evaluate the fitness f (x) of each chromosome x in the population.

3. New population: Create a new population by repeating the following steps until the new population is complete.

4. Selection: Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to get selected).

5. Crossover: Cross over the parents to form new offspring (children). If no crossover was achieved, offspring is the exact copy of parents.

6. Mutation: With a mutation probability, mutate new offspring at each locus (position in chromosome)

7. Accepting: Place new offspring in the new population.

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8. Replace: Use new generated population for a further sum of the algorithm.
9. Test: If the end condition is satisfied, stop, and return the best solution in current population.
10. Loop: Go to step2 for fitness evaluation.

IV. Simulation and Results

Simulation is carried out using MATLAB R2009a.

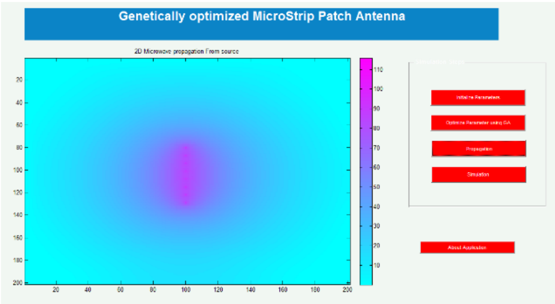

Figure 4: Graphical User Interface (GUI) for the proposed work

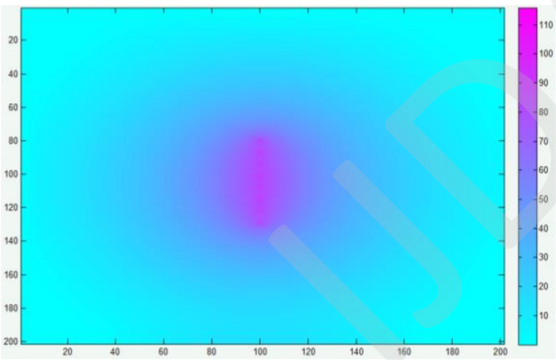

Figure 5: 2D Microwave propagation from Sine Wave source

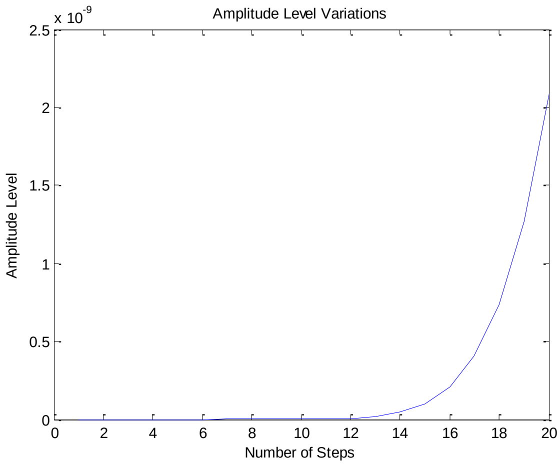

Figure 6: Amplitude level variations with number of steps

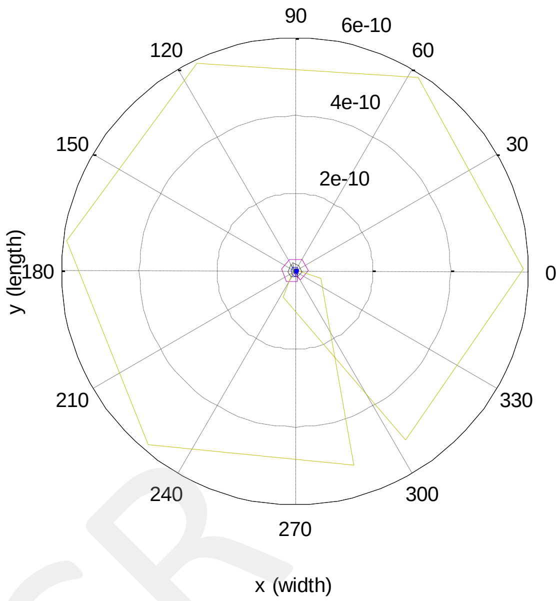

Figure 7: Polar plot of field distribution

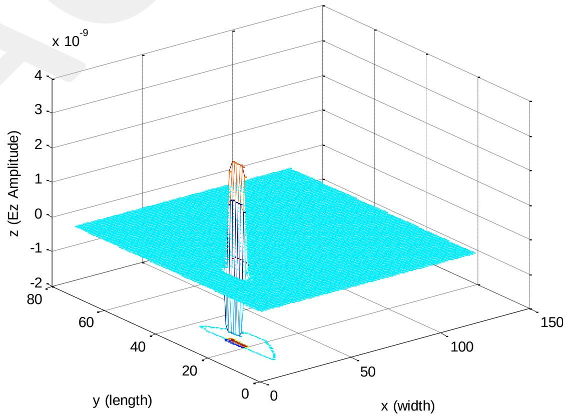

Figure 8: Distribution of electric field towards z direction

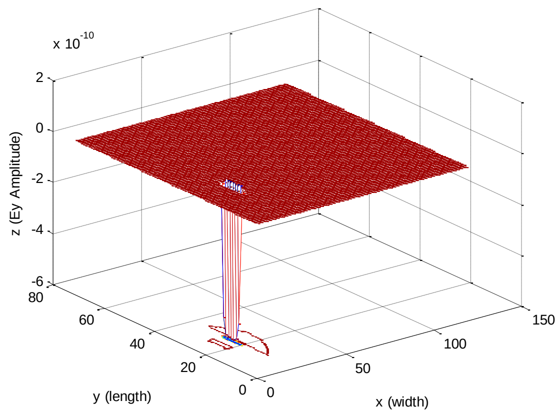

Figure 9: Distribution of electric field towards y direction

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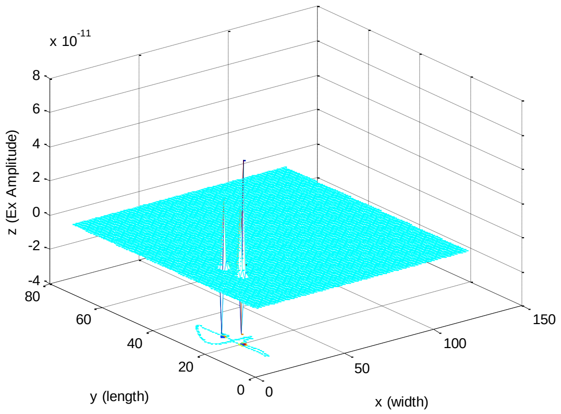

Figure 10: Distribution of electric field towards x direction

V. Conclusion

H-shaped antenna has comparatively smaller size than the conventional antennas hence it provides a better set of results than the other rectangular shaped patch antennas. The parameters of this antenna are studied in this paper. An FDTD method is applied to study this antenna. From input, parameters are set through genetic algorithm in order to make the fitness function minimum to get optimum results. Results have shown that the reduction in the size of the center strip reduces the antenna size in an efficient way. Finally radiation patterns in the E and H-planes for the H-shaped patch antenna with different center strip widths are ours aimed results.

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