Genetic Algorithm Optimization and Performance Comparative Analysis of Rectangular, Triangular and Circular Patch Antennas for X Band Applications

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Abstract—The growth of portable wireless communication devices has pushed designers to design miniature size antennas. The most prized among miniature antenna choices is the micro-strip patch antenna. These antennas have significant advantages such as low profile, light weight, relatively low manufacturing cost, and polarization diversity. In this paper Genetic Algorithm optimization technique has been utilized for dimensions optimization of three types of patch antennas in addition to the comparative performance analysis of rectangular, triangular and circular shape microstrip patch antennas at X band frequency in order to list the advantages of each shape and decide which shape is best suited for the desired frequency. The resonant frequency is chosen at 11 GHz which is suitable for a variety of wireless applications. Ansoft HFSS is used as the software environment to design and compare the performance of the antennas in terms of return loss, VSWR, directivity and radiation beam-width. A program has been developed in MATLAB for obtaining the patch antennas dimensions based on theoretical formulas and various important performance metrics are analyzed for performing comparative analysis between un-optimized and optimized multi-shape patch antennas design. The results show that the circular patch antenna has a very good value of return loss -44.42 dB and an improved VSWR value of 1.01 than those of other patch shapes. However, rectangular patch antenna is more directive, it has 9 dB in directivity and 61° in radiation beam-width at E-plane.

Keyword-Circular patch antenna, Directivity, Genetic algorithm, HFSS, Rectangular patch antenna, Return loss, Triangular patch antenna.

I. INTRODUCTION

In the area of modern world where communication has become indispensable, antennas are rightly to be said as electronic eyes and ears of the world due to their undeniable place in the communication technology. While, the revolution in antenna engineering leads the fast growing communication systems, Microstrip Patch Antennas have been one of the most innovative developments in the era of miniaturization [1, 2, 3].

Microstrip Patch Antennas are increasingly finding their applications in a broad range of microwave systems from radars, telemetry, navigation, biomedical systems, mobile and satellite communications, missile systems, global positioning system (GPS) for remote sensing and etc. because of their light weight, low volume, low cost, low profile, ease of fabrication, conformability to mounting hosts and ability to be printed directly onto a circuit board [4].

These antennas consist of a metallic radiating patch element, embedded into a grounded dielectric substrate. The shape of the conducting patch can be of any geometrical form among which rectangular, triangular and circular are the most common [5, 6]. The rectangular, triangular and circular Microstrip patch antennas are used as simple and for the extensive and most demanding applications as they easily provide with feed line flexibility, multiple frequency operation, linear and circular polarizations, frequency agility, good bandwidth etc.

Another reason for the popularity of these patch antennas is their compatibility to array configurations. Rectangular, triangular and circular patches are very popular shapes for microstrip patch antenna array constructions [7, 8, 9].

After all, Microstrip patch antennas have some major disadvantages as low gain and low power handling capability. A low gain of approximately 5 dB is the most major limiting factor for the widespread applications of Microstrip Patch Antennas. Therefore, to overcome these limitations several methods have been introduced which includes different types of feeding mechanisms for high gain [10] and various existing optimization algorithms which can come handy in this case, genetic algorithm which is one of the global optimization algorithms has been used widely in the past by antenna designers [11-12] for the optimization of the patch shape and size in order to achieve better overall performance of the antenna.

In this paper genetic algorithm has been used for optimization of inset feed rectangular, triangular and circular microstrip patch antennas dimensions, It was exactly used to optimize the rectangular patch length and width, the equilateral length of the triangular patch and the radius of the circular patch. Therefore we are presenting a comparison analysis of the three shape patch antennas, three resonant at the frequency of 11 GHz, in the X band which has applications in Satellite Communication, Radar Engineering, Space Communications etc. The work has been performed by interfacing the genetic algorithm to Ansoft High Frequency Structure Simulator (HFSS). The paper is organized as follows:

Section II presents the design specifications and genetic algorithm optimization of the three types of antennas. The simulated results are discussed in Section III and finally Section IV provides the conclusion and future work.

II. ANTENNA DESIGN SPECIFICATIONS

A. Theoretical Formulation

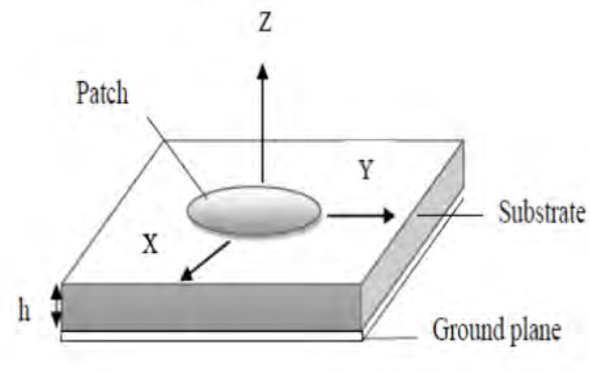

Fig. 1. Microstrip patch antenna geometry

The microstrip patch antenna consists of three layers Fig .1, the dielectric substrate is placed between a ground plane (lower layer) and radiating metallic patch (top layer).The dimensions of radiating patch are calculated by appropriate equations depending on the patch shape (rectangular, circular or triangular) [1].

1) Rectangular Patch Antenna: The formulas to determine the rectangular patch dimension are as follows [1]:

The width of the patch can be written as:

$$\mathrm{W} = \frac{c}{2fr\sqrt{\frac{2}{\varepsilon r+1}}} \quad (1)$$

The length of the patch becomes:

$$\mathrm{L} = \mathrm{L}_{eff} - 2\Delta\mathrm{L} \quad (2)$$

Where the extension in length due to fringing effect:

$$\frac{\Delta L}{h} = 0.412\ \frac{(\varepsilon eff+0.3)\left(\frac{W}{h}+0.264\right)^{1}}{(\varepsilon eff-0.258)\left(\frac{W}{h}+0.8\right)^{1}} \quad (3)$$

And the effective dielectric constant:

$$\varepsilon eff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+\frac{12\mathrm{h}}{W}\right)^{-1/2} \quad (4)$$

This equation is based on Transmission Line model.

2) Circular Patch Antenna: The radius of the circular patch is given by [1]:

$$\mathrm{r} = \frac{\mathrm{F}}{\left\{1+\frac{2\mathrm{h}}{\pi\varepsilon\mathrm{r}\mathrm{F}}\left[\ln\frac{\pi\mathrm{F}}{2\mathrm{h}}+1.7726\right]\right\}^{1/2}} \quad (5)$$

Where $\mathrm{F}=\frac{8.791*10^{9}}{\mathrm{fr}\sqrt{\varepsilon\mathrm{r}}}$ (6)

This equation is based on Cavity model.

3) Triangular Patch Antenna: The equilateral length of the triangular patch is given by [1]:

$$a=\frac{2c}{3fr\sqrt{\varepsilon r}} \qquad (7)$$

This equation is also based on Cavity model.

Inset length of the three patch (triangular, circular and triangular) for inserting microstrip feed line is [12]:

$Y_0 = 10^{-4}\,[0.001699\,\varepsilon r^{7} + 0.13761\,\varepsilon r^{6} - 6.1783\,\varepsilon r^{5} + 93.187\,\varepsilon r^{4} - 682.69\,\varepsilon r^{3} + 2561.9\,\varepsilon r^{2} - 4043\,\varepsilon r^{1} + 6697]\,\frac{L}{2}$ this expression is valid for $2 \leq \varepsilon r \leq 10$. (8)

B. Design Parameters Optimization

GA's are the search algorithms based on the mechanics of natural selection and natural genetics. They are stochastic search procedures modelled on the Darwinian concepts of natural selection and evolution. In GA a set or population of potential solutions is caused to evolve towards a global optimal solution. GA optimization technique is different from local optimization techniques which produce results that are highly dependent on the starting point or initial guess. GA's can handle discontinuous and non-differentiable functions. They are also well suited for constrained optimization problems.

TABLE I
Important Terms related to Genetic Algorithm

Genetic Term	Meaning
Allele	Characteristic value
Gene	It is a coded optimization parameter
Chromosome	A trial solution vector consisting of genes
Generation	Successively created populations
Child	A member of next generation
Parent	A member of next generation
Fitness	Evaluation Criteria
Reproduction	Process of producing new solution based on fitness value
Population	Set of trial solutions
Crossover	It is a process of producing new solution from crossover principle
Mutation	Change in the value within the chromosome

Table I gives a brief about various important terms related to genetic algorithm. Fitness function is the only connection between the physical problem being optimized and the genetic algorithm. Fitness function is used to assign a fitness value to each of the individuals in the GA population. Fitness value returned by the fitness function is in some manner proportional to the goodness of a given tried solution in generation. GA starts with coding the unknown variables into chromosome, randomly generating N number of solutions. The chromosomes are weighted based on their fitness function values and the inferior ones will be updated by selection, crossover and mutation operations. Optimization is terminated when stopping criteria is met.

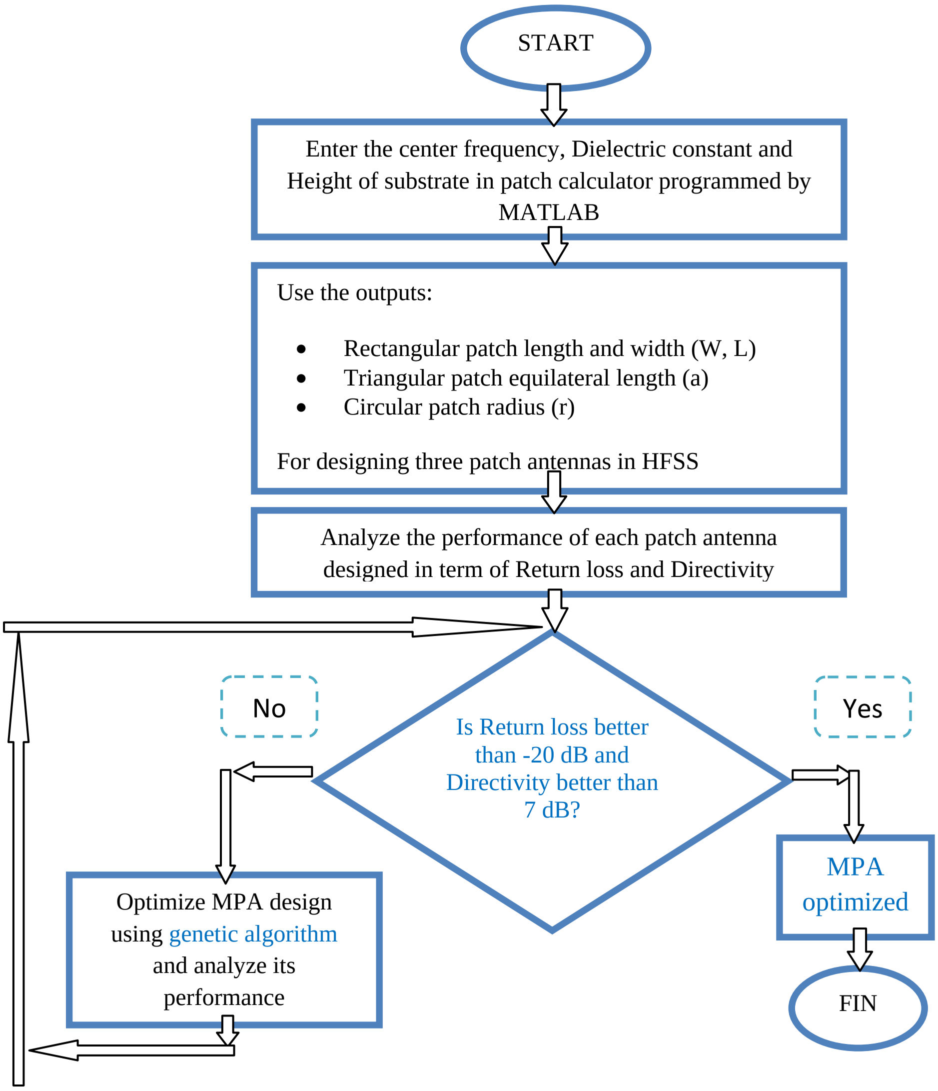

Fig.2 Flow chart showing use of GA in optimization of MPA design

Figure 2 shows the flow chart used to optimize the design of rectangular, triangular and circular MPA. First, we calculate the antenna parameters then we analyse its performance, if the results are not satisfied we use genetic algorithm optimization. Optimization is terminated when criteria is met.

The proposed microstrip patch antennas are realized on the Roger RT/duroid substrate with permittivity ε_r=2.2 and thickness (h) of substrate is 0.79 mm, the ground plane and radiating patch are made of copper. The operating frequency of antennas (fr), at which we wish to achieve the better performance, is 11GHz.

The geometry of the antennas analysed is shown in Fig 2, 3, 4. The Performance of the microstrip antenna depends on its dimension, the operating frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced [1]. For an efficient radiation, the patch antennas have been designed with the optimized parameters according to the table below:

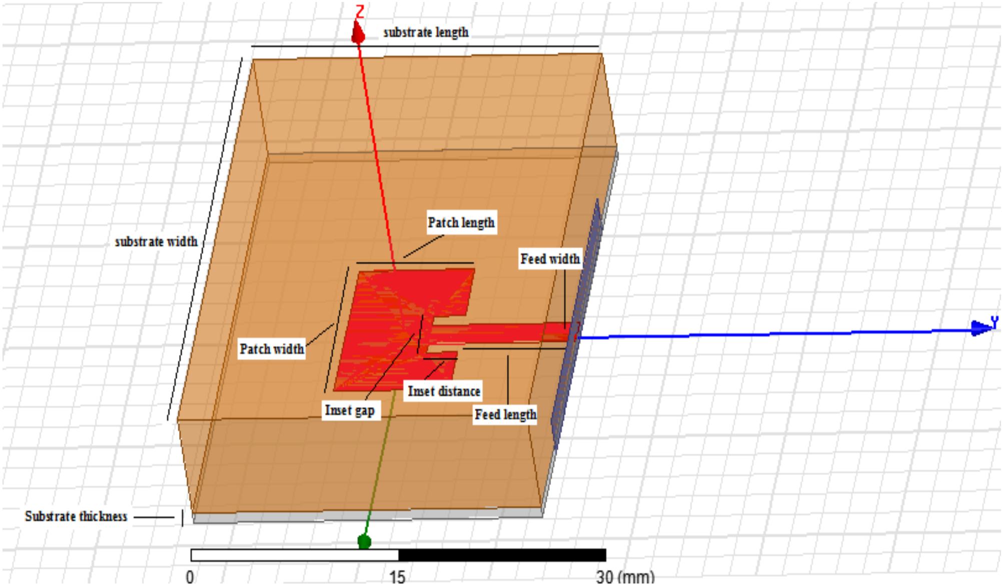

Fig. 2. Rectangular patch antenna geometry

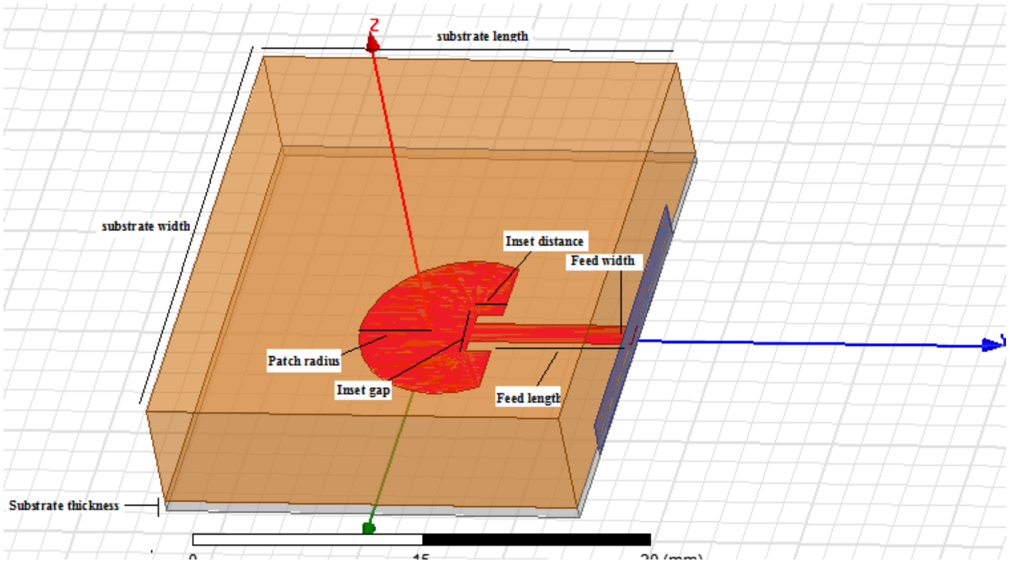

Fig. 3. Circular patch antenna geometry

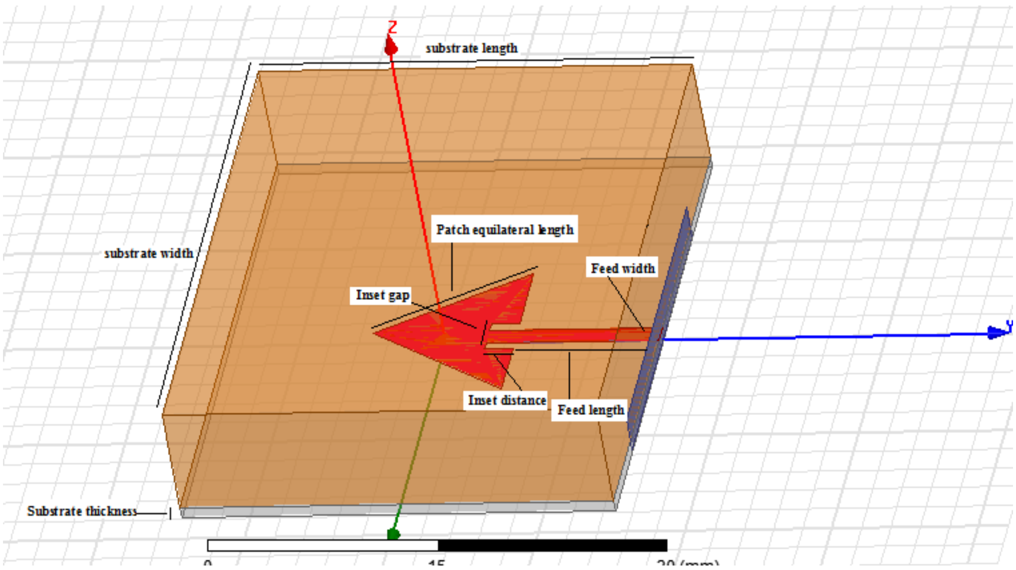

Fig. 4. Triangular patch antenna geometry

TABLE I
List of Optimized Design Parameters of Rectangular, Circular and Triangular Patch Antenna

Symbol	Parameter (mm)	Rectangular Patch	Circular Patch	Triangular Patch
Ls	Substrate Length	28	28	28
Ws	Substrate Width	35	35	35
h	Substrate Thickness	0.79	0.79	0.79
W	Patch Width	11.86	-	-
L	Patch Length	9.31	-	-
r	Patch Radius	-	5.93	-
a	Patch Equilateral Length	-	-	15
W_f	Feed Width	2.408	2.408	2.408
L_f	Feed Length	9.31	9.31	9.31
g	Inset Gap	1.204	1.204	1.204
Y_0	Inset Distance	2.155	2.155	2.155

Below, we will present the simulation results in terms of the computed radiation patterns, return loss and directivity of the proposed antennas. We use HFSS, which is 3D High Frequency Structure Simulator software [14].

III. SIMULATION RESULTS & DISCUSSION

Now-a-days, it is a common practice to evaluate the system performances through computer simulation before the real time implementation. A simulator “Ansoft HFSS” based on finite element method (FEM) has been used to calculate return loss, VSWR, radiation beam-width and directivity. This simulator also helps to reduce the fabrication cost because only the antenna with the best performance would be fabricated.

Genetic algorithm is one of the EM optimization techniques integrated with Ansoft HFSS. This can be utilized to reduce the efforts of manual tuning of the patch dimensions in order to achieve the desired goal.

Genetic Algorithm parameters are given below:

Error function limit = 0.001

Standard deviation = 0

Maximum number of generations = 1000

Population size = 50

Mutation Rate = 0.2

Crossover Rate = 0.3

Random search = 0

Iterations = 50

A. Impact of Patch Shape on Return Loss

Figure 5 shows the comparison of return loss of various optimized microstrip patch antennas having different shapes of the patch. It is observed that at the resonant frequency (11 GHz) the return loss value of the circular patch antenna is -44.42 dB, whereas for triangular and rectangular patch antenna the return loss has a value of -33.97 dB and -25.51 dB respectively. The result shows that the circular patch has the best return loss in comparison to other shapes. Therefore, the circular patch antenna present better impedance matching instead of using the same feeding dimensions for triangular and rectangular patch.

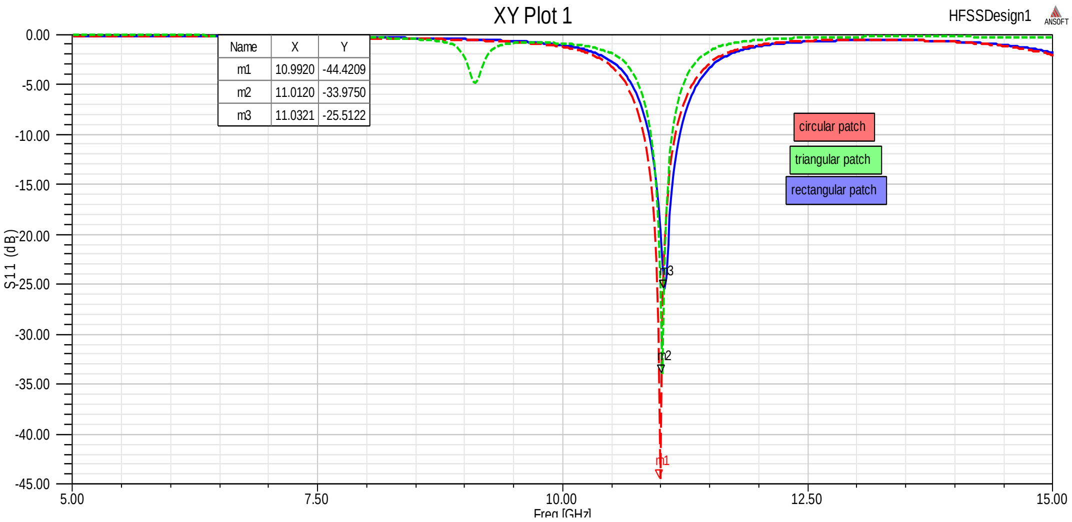

Fig. 5. S- Parameter plot of circular, triangular and rectangular patch antenna

B. Impact of Patch Shape on VSWR

Figure 6 shows the comparison of VSWR of various optimized microstrip patch antennas having different shapes of the patch. It is observed that at the resonant frequency (11 GHz) the VSWR value of the circular patch antenna is 1.01, whereas for triangular and rectangular patch antenna the VSWR has a value of 1.04 dB and 1.11 dB respectively. The result shows that all antennas exhibit good VSWR (1-2) but the circular patch has the best one (closer to the ideal value VSWR=1) compared to other shapes.

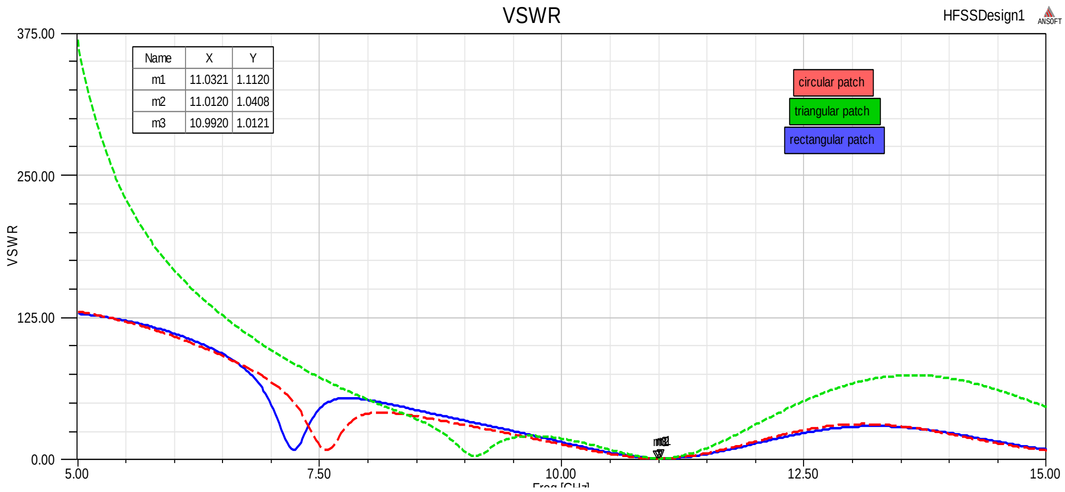

Fig. 6. VSWR- Parameter plot of circular, triangular and rectangular patch antenna

C. Impact of Patch Shape on Directivity

Figure 7 shows the comparison of Directivity plot of various optimized microstrip patch antennas having different shapes of the patch. It can be seen that the directivity occurs with approximately same value for circular and triangular patch antenna (about 8 dB), however the rectangular patch antenna has a better value of 9 dB at the resonate frequency. So it is evident that circular patch antenna is more directive when compared to the rectangular and triangular patch antennas.

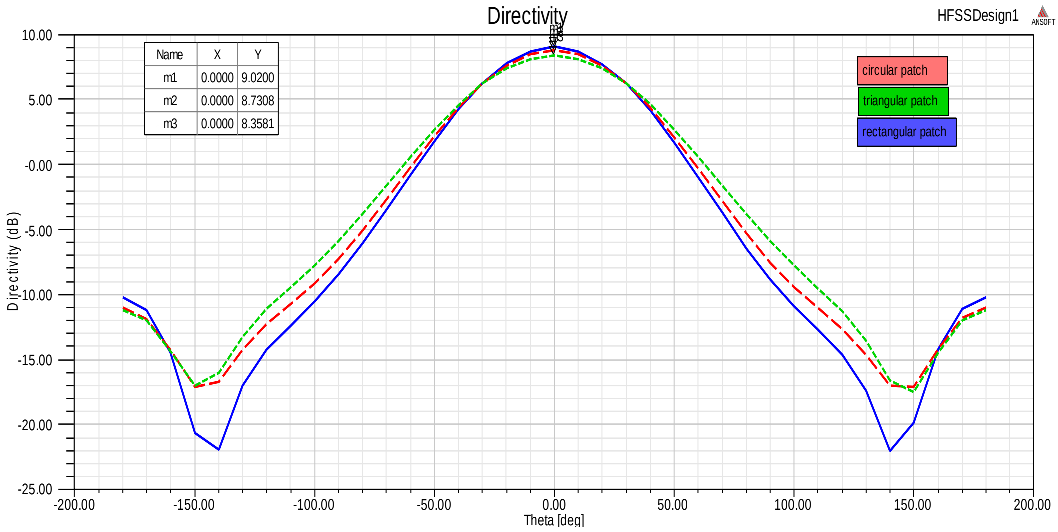

Fig. 7. Directivity plot of circular, triangular and rectangular patch antenna

D. Impact of Patch Shape on Gain

From the 3D radiation pattern plot (Fig.8, Fig.9 and Fig.10) the gain of the proposed antennas can be calculated. The triangular patch antenna has a gain of 7.89 dB, the circular patch antenna has a gain of 8.42 dB while the gain of rectangular one is 8.72 dB. So the rectangular patch antenna is better in term of gain than other patch shapes.

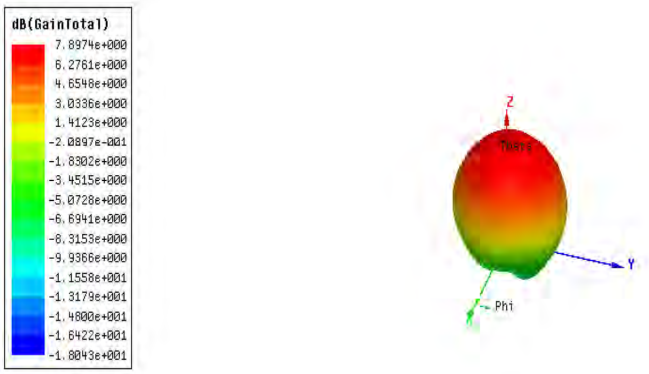

Fig. 8. 3D Radiation pattern of triangular patch antenna

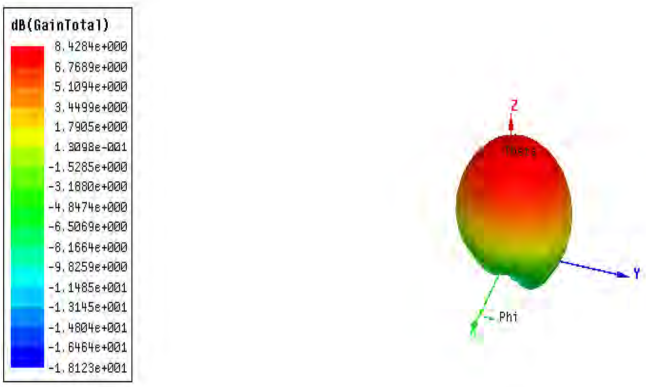

Fig. 9. 3D Radiation pattern of circular patch antenna

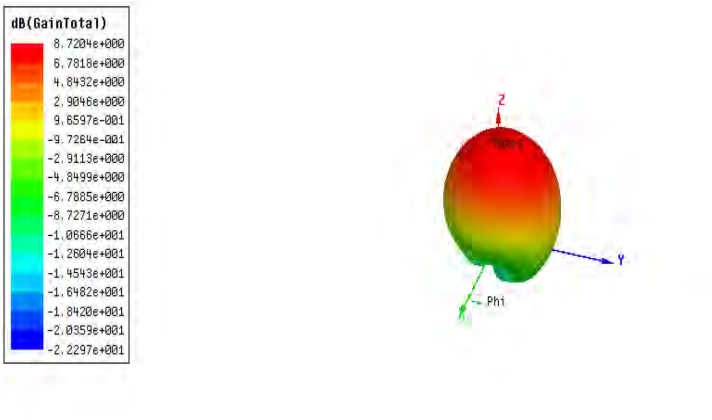

Fig. 10. 3D Radiation pattern of rectangular patch antenna

E. *Impact of Patch Shape on Radiation Beam-Width*

Figure 11 shows the comparison of Radiation pattern of various optimized microstrip patch antennas having different shapes of the patch. All the patch shapes have almost same radiation pattern at E-plane.

The radiation beam-width at E-plane of circular and triangular patch antenna is 65° and 70° respectively.), however the rectangular patch antenna has a better value of 61° at the same plane. Therefore the rectangular patch antenna provides a narrower beam-width along the forward direction.

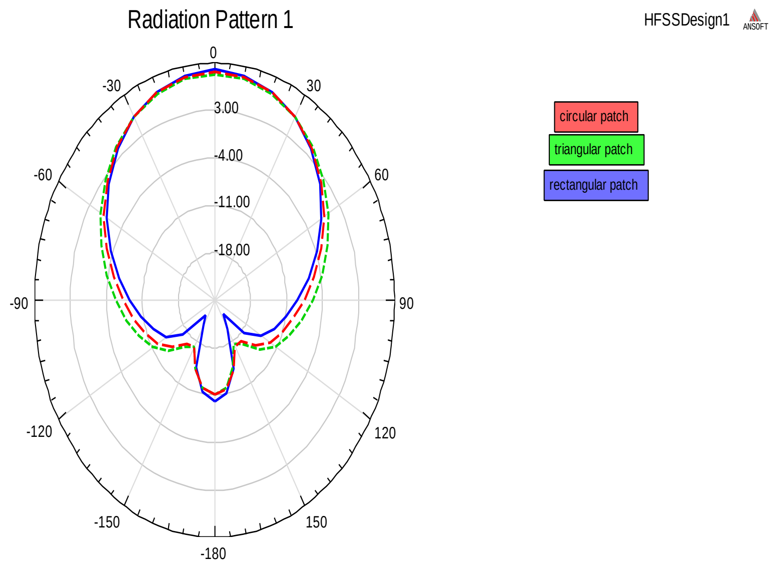

Fig. 11. Radiation pattern plot of circular, triangular and rectangular patch antenna at E-plane

F. *Comparative Analysis of Microstrip Antennas for Basic Patch Shapes*

The overall comparison of different performance parameters of rectangular, circular and triangular patch antennas have been summarized in table II. From perspective of return loss and VSWR, circular patch antenna shows superiority over the rectangular and triangular patch, and when directivity, gain and radiation beamwidth are considered rectangular patch antenna becomes superior over all patch shapes. However, both the rectangular and circular patch antennas exhibit same radiation efficiency which make them compatible for similar applications.

TABLE II
Comparison of performance parameters

Patch Antenna Parameters	Triangular	Circular	Rectangular
Frequency	11.01 GHz	10.99 GHz	11.03 GHz
Return Loss	-33.97 dB	-44.42 dB	-25.51 dB
VSWR	1.04	1.01	1.11
Directivity	8.35 dB	8.73 dB	9.02 dB
Gain	7.89 dB	8.42 dB	8.72 dB
Beam-Width	70°	65°	61°
Radiation Efficiency	89.935 %	93.274 %	93.334 %

IV. CONCLUSION

Genetic algorithm optimization of a rectangular, circular and a triangular patch antennas parameters and performance comparative analysis using the simulation results obtained from Ansoft HFSS software have been carried out. The circular patch antenna shows good results on perspectives of return loss and VSWR which indicates perfect matching. However, the rectangular patch antenna shows better performance in terms of directivity, gain and radiation beam-width. The triangular patch antenna show quite good performances compared to other patch shapes but it has small physical size that make it used to overcome the drawbacks of designing cost. The three antennas present good radiation efficiency at X band frequency (11 GHz) and can be used for the same applications of Satellite Communication, Radar Engineering etc. In the future, the work will be carried out for circular, triangular and rectangular patch antennas with EBG structure used as substrate and superstrate at X band frequency.

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