DOI: 10.21917/ijct.2011.0053

DESIGN OF MICROSTRIP RADIATOR USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

Yogesh Kumar Choukiker[1] and Santanu Kumar Behera[2]
Department of Electronics and Communication Engineering, National Institute of Technology, Rourkela, India
E-mail: [1]yogesh.ku.84@gmail.com and [2]prof.s.k.behera@gmail.com

Abstract
An inset feed Microstrip radiator has been designed and developed for operation at 2.4GHz frequency. The Microstrip patch antenna (MPA) parameters were designed using IE3D®TM EM simulator (version 14.0) and optimized with an evolutionary stochastic optimizer i.e. Particle Swarm Optimization (PSO) technique. Optimized results show that the antenna has a bandwidth of 33.54 MHz (<-10dB) in the range 2.38355 GHz to 2.41709 GHz and a maximum return loss of -43.87dB at the resonant frequency of 2.4 GHz. The patch antenna is fabricated and the important parameters like return loss, VSWR etc were measured. The measured parameters match with the simulated results well within the tolerable limits.

Keywords:
IE3D®TM EM Simulator, PSO, Inset Feed, Microstrip Patch Antenna

1. INTRODUCTION

Microstrip antennae are popular for their attractive features like: light weight, low profile, ease of fabrication and compatibility with Monolithic Microwave Integrated Circuits (MMICs). The patch antennae are used in satellite communication, wireless and microwave applications due to their compact and planar structures[1-3].The main disadvantage is an intrinsic limitation in bandwidth due to the resonant nature of the patch structure. Intensive research has been done to develop bandwidth enhancement techniques for MPAs [4-6]. The most popular methods for enhancement of bandwidth are increasing the height of the substrate and adding parasitic elements to the patch. This process can lead to surface wave loss.

The fast and accurate simulation of an antenna design on a PC or parallel platforms has opened the door for stochastic optimizers to augment design processes in a large variety of Engineering EM problems. The Particle Swarm Optimization (PSO) algorithm is one of them. Its applications have received massive attention in recent years. As a novel evolutionary algorithm [7] proposed in mid 1990's, PSO has been introduced into the EM community by one of the authors of reference [8-13] and its applications have received enormous attention in recent years. Unlike genetic algorithms (GAs) [14], which rely on Darwin's theory of natural selection and the competition between individual chromosomes, the swarm intelligence in the nature is modeled by fundamental Newtonian mechanics in PSO for optimization purposes. This corporative scheme manifests PSO the concise formulation, the ease in implementation and many distinct features in different types of optimization techniques.

At present a variety of EM simulators are commercially available. **IE3D®TM** EM Simulator is one of them. In this paper the patch antenna is designed using **IE3D®TM** Simulator. The inbuilt optimization softwares in **IE3D®TM** are insufficient for optimization of the designed parameters of the antenna [15].

Therefore, in this article, the authors attempt to use optimization techniques to develop a soft computing tool by linking PSO with **IE3D®TM** EM simulator in order to get objective functions like(S-parameter, VSWR, bandwidth etc) of a Microstrip patch antenna.

2. DESIGN OF MICROSTRIP RADIATOR USING IE3D®TM-PSO

This section presents the geometry of the Microstrip radiator using inset feeding technique. Basic architecture of Particle Swarm Optimization is also described along with expressions for velocity and position of particles.

2.1 GEOMETRY OF THE PATCH

In Microstrip patch antenna, feeding mechanism plays an important role in the design of a patch. A patch antenna can be fed either by coaxial probe or by an inset Microstrip line. Coaxial probe feeding is easy to fabricate, while Microstrip line feeding is suitable for developing high gain Microstrip antennas. In both the cases, the probe position or the inset length determines the input impedance.

The Fig.1 shows an inset fed Microstrip patch antenna. The dielectric constant of the substrate, thickness, patch length, patch width, feed line width, span and feed line distance are denoted as ε_r, h, L,W, W_f, S, and y_0.

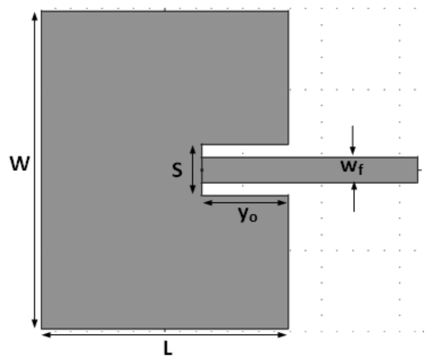

Fig.1. Schematic of Inset-fed Microstrip Patch Antenna

In Microstrip patch antenna the feed line impedance (50Ω) is always same as the resistance at the edge of the patch which is usually few hundred ohms depending on the patch dimensions and the substrate used. As a result the maximum power is not being transferred and input mismatch affects the antenna performance. The input impedance of the rectangular Microstrip patch antenna decides the matching between feed line and patch.

According to the Transmission line theories, the resistance of the patch varies as a Cosine squared function along the length of the patch.

The antenna structure (Fig.1) consists of a rectangular patch dimension W × L using inset planar feed having the dielectric constant of 2.4 and height (h) of 1.58 mm. In IE3D®TM simulator various optimization tools such as Powel, Random, Genetic and Adaptive are available. The parameters defined by IE3D®TM are generally controlled by bound and direction with fixed rate. It has been observed that for any variations of the optimization parameters, overlapping problems arise in the IE3D®TM simulation and the iterations terminate prematurely with an error. This error can be minimized by using the powerful optimization tool but IE3D®TM cannot deal directly with the external optimizer. Hence the new design optimizer is used here to optimize the antenna parameters using PSO.

2.2 PARTICLE SWARM OPTIMIZATION (PSO) ARCHITECTURE

Evolutionary computation exploits a set of potential solutions, named population, and detects the optimal ones through co-operation and competition among the individuals of the population. Particle Swarm Optimization (PSO) is one of the population-based stochastic optimization technique inspired by social behavior of bird flocking. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA) , Ant colony etc. PSO developed by Kennedy and Eberhart [7] in 1995, is based on the behaviour of swarm of bees or flock of birds while searching for food. In PSO, the individuals, called particles, are collected into a swarm and fly through the problem space by following the optima particles. Each individual has a memory, remembering the best position of the search space it has visited. In particular, particle remembers the best position among those it has visited and the best position by its neighbours. Each individual of the population has an adaptable velocity (position change), according to which it moves in the search space. Thus, its movement is an aggregated acceleration towards its best previously visited position and towards the best individual of a topological neighborhood. The evolution of particles, guided only by the best solution, tends to be regulated by behaviour of the neighbours.

In the initial stage PSO is developed for single objective optimization. The particles are generated using MATLAB®TM programming and linked to IE3D®TM to obtain data for optimization. The optimized antenna is then fabricated and experimental results are compared with the simulated results.

The antenna parameters to be optimized (e.g. length & width) shall form the position of the particle. A set of such positions shall be taken initially. Fitness of each position are evaluated based on an objective function. The objective function is a function of the position being evaluated, other parameters of the antenna given as input (e.g. substrate dielectric constant, substrate thickness, substrate size etc) and the desired antenna characteristics.

Each individual (called particle) in the swarm has cognitive behaviour as well as social behaviour together with random local search behaviour. The location of highest fitness value personally discovered by a particle is called pbest (personal best); and the location of highest fitness function discovered by the swarm is called gbest (global best). These values are always kept up to date during the iterations of the algorithm. In this article, the position of a particle represented by a point in the N-dimensional space is analogous to a bird's place in the field. This N-dimensional space is the solution space for the problem being optimized. The velocity of a particle represents the magnitude and the direction of the movement and changes according to its own flying experience and the flying experience of the best among the flock. The flow chart of the optimization process is shown in Fig.2. A fitness function is first designed to verify the performance of each candidate solution. Then each particle starts to move from a random position with a random velocity. The manipulation of a particle's velocity is the key element for the success of PSO. The velocity of each particle is changed so that it is accelerated in the directions of pbest and gbest as per the Eq.(1) and Eq.(2) [16-18].

$$V_i(t+1) = U * V_i(t) + C_1 * \eta_1 * \left(X_{pbest}(t) - X_i(t)\right) + C_2 * \eta_2 * \left(X_{gbest}(t) - X_i(t)\right) \quad (1)$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (2)$$

In the above, $V_i(t)$ is the velocity of the particle in the ith dimension; $X_i(t)$ is the particle's coordinate in the ith dimension and 't' denotes the current iteration, 'U' is a time-varying coefficient, which usually decreases from 0.9 to 0.6 linearly, C_1 & C_2 are two random constants usually fixed to be 2.0, η_1 & η_2 are two random functions applied independently to provide uniform distributed numbers in the range from 0 to 1. The calculation continues for each of the dimensions in an N-dimensional optimization problem. X_{pbest} records the ith particle's position which attains its personal best fitness value while X_{gbest} records the position which attains its global best fitness value among all.

3. METHOD OF DESIGN AND OPTIMIZATION

The flow chart is shown below to link IE3D®TM with PSO.

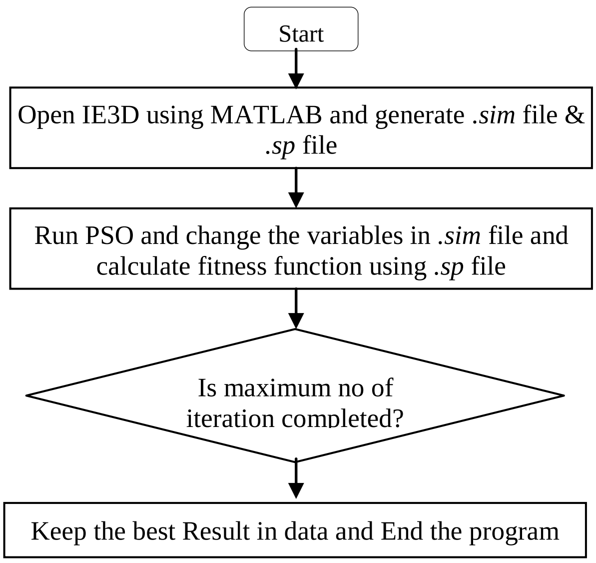

Fig.2. Flow chart of IE3D-PSO

The different values of length (L), width (W), Inset depth (y_0) and Span(S) are varied from lower to higher to get the optimized values of the conventional antenna, shown in Table.1. Here the value of L in the conventional antenna was 39.6mm. Therefore L was varied from 30 to 50mm with an increment of 1 mm. Similarly, for getting width of 49mm, W was varied from 40 to 60mm and inset depth & span length were varied accordingly. The optimized values are presented in Table.2.

Table.1. Design parameter of patch antenna (ε_r=2.4, h=1.58) (all dimension in mm)

Bounds	Length	Width	Inset Depth	Span
Lower	30	40	5	0
Higher	50	60	20	10

Table.2. Optimization parameter of patch antenna using IE3D-PSO (ε_r=2.4, h=1.58) (all dimension in mm)

Length	Width	Inset Depth	Span
39.6226	49.0	13.2726	5.672

The design method is described above flow chart to interface between IE3D®TM-PSO in Fig.2. The variables for optimization defined by IE3D®TM are saved in a .sim file, and the simulated results of return loss are saved in a .sp file. By changing the variables saved in the .sim file using the MATLAB®TM (Version: 7.6) developed for PSO technique. Fitness function value is obtained by calculating the simulated results saved in the .sp file. The design parameters for the antenna are listed in Table.1 and the optimized parameters are listed in Table.2. The optimization is executed using a 10-agent swarm for 1000 iterations. The antenna is designed at 2.4 GHz frequency and basis of this frequency the fitness function is defined as:

$$\text{Fitness} = \min\left(S_{11n}^{2} \right) \quad (3)$$

4. OPTIMIZATION AND SIMULATION RESULTS

The simulated results of antenna performances such as return loss and radiation pattern are discussed in this section. This optimized result is simulated using Zealand's IE3D®TM simulation package (version 14.0) and the simulated return loss curve is shown in Fig.3. It shows a maximum return loss of -43.87dB in the resonant frequency of 2.4 GHz and the bandwidth of 33.54 MHz below -10dB ranges from 2.38355 GHz to 2.41709 GHz. The plot of radiation patterns in Polar form is shown in Fig.4. The maximum gain of 6.67 dBi in the broadside direction for both V = 0^0 and V = 90^0 and a half power beam-width (HPBW) of 78^0 are obtained. Gain vs frequency plot is shown in Fig.5. The Fig.6 shows the convergence curves of IE3D-PSO. A large bandwidth except only a slight frequency shift in the resonance is achieved by this method. The simulation work was carried out in a HP Mobile Work Station (Model: 8530W) with 2.66 GHz processor & 2GB RAM. It took around 6-Hours to complete the simulation work.

5. EXPERIMENTAL RESULTS

A prototype of proposed patch antenna with operating frequency 2.4 GHz was fabricated on Ultralam® 2000 substrate with Dielectric constant (ε_r) of 2.4 and thickness(h) of 1.58mm. The return losses and VSWR of the antenna are measured on Agilent Technologies™ E5071C (9KHz – 4.5Ghz) network analyzer. Fig.7 and Fig.8 shows the performances of return loss and VSWR measurement for the antenna. It is seen that the performances match closely with simulated results. It is also observed that the antenna design provides a good bandwidth except only a slight frequency shift in the resonance.

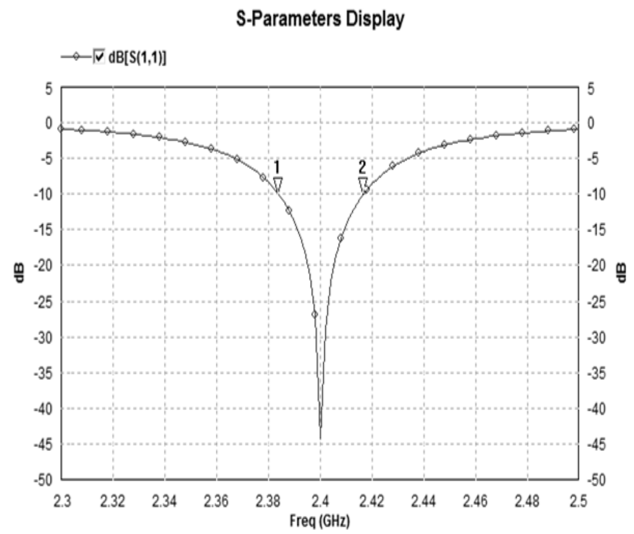

Fig.3. Simulated Return Loss at 2.4GHz

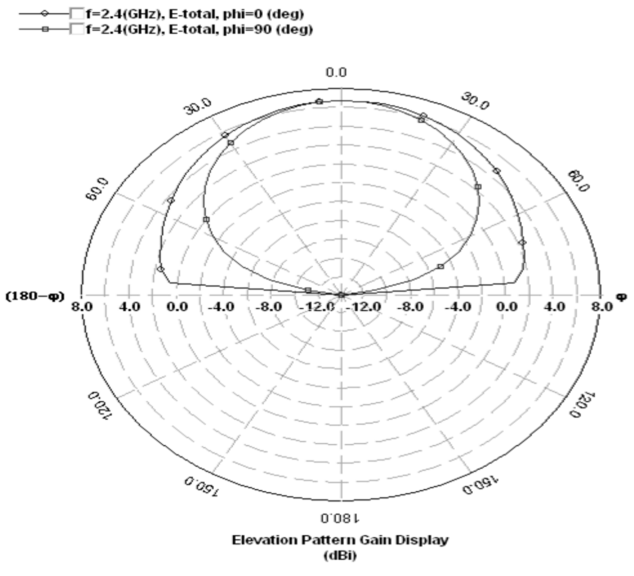

Fig.4. Simulated Radiation Pattern (E & H plane)

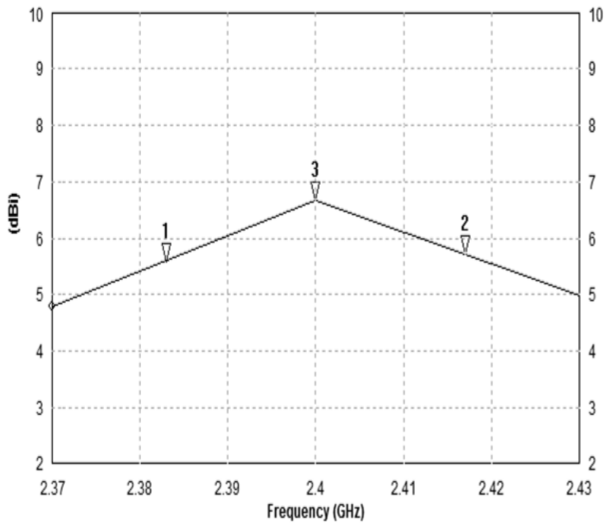

Fig.5. Gain vs Frequency

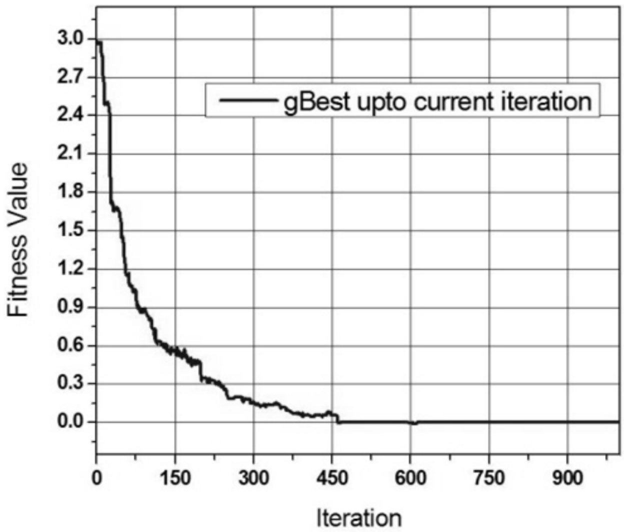

Fig.6. Convergence curves of IE3D-PSO optimization

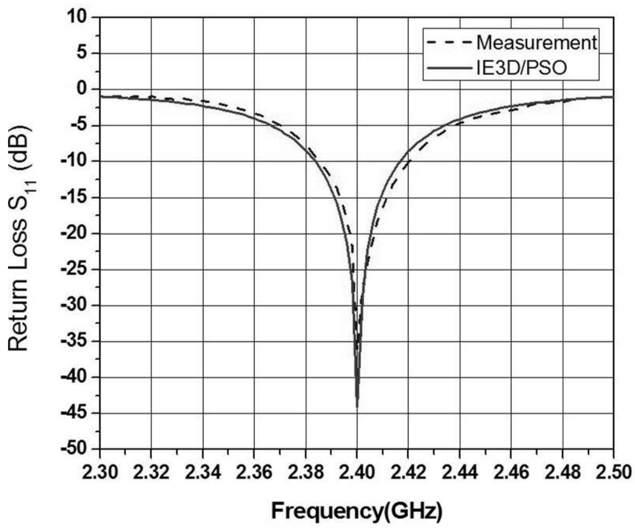

Fig.7. Simulated and measured S11 curves of optimized patch antennas

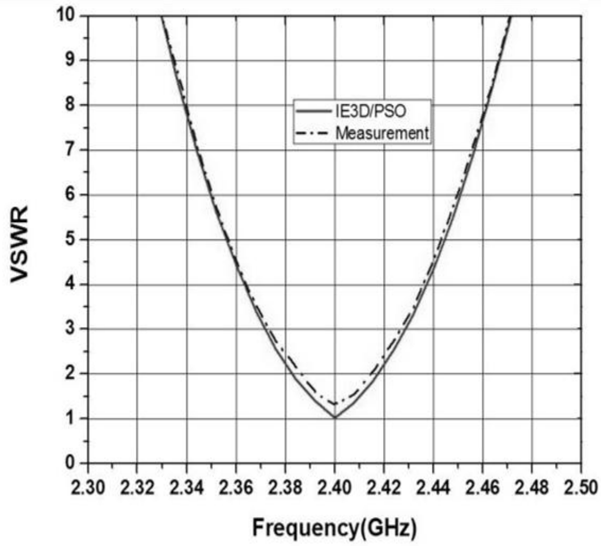

Fig.8. Simulated and measured VSWR curves of optimized patch antennas

6. CONCLUSION

The design optimization of an inset feed patch antenna has been implemented combining an efficient evolutionary optimization method (PSO) with a standard electromagnetic simulator (IE3D). The accuracy, robustness and ease of implementation of this method validate its potential application in patch antenna design. This method can also be effectively used in the design of various complex microwave and millimeter-wave circuits. The performance of the IE3D-PSO combined antenna design presented in Fig.7 & Fig.8 establishes the fact that IE3D alone is insufficient for precision design of antenna elements for high frequency applications.

REFERENCES

[1] Balanis Constantine A, "*Antenna Theory, Analysis and Design*", John Wiley & Sons, 2nd Edition, 2005.

[2] D.M. Pozar, "Microstrip antennas", *IEEE Transaction on Antenna and Propagation*, Vol. 80, No. 1, pp. 79-91, 1992.

[3] R. Waterhouse, "Small Microstrip patch antenna," *Electron. Letters*, Vol. 31, No. 8, pp. 604-605, 1995.

[4] R Garg, P. Bhartia, I. Bahl and A. Ittipiboon," *Microstrip antenna Design Handbook*", Chapters 3 & 4, Artech House, Boston, London, 2001.

[5] K. L. Lau, K. M., Luk and K. F., Lee, "Design of a circularly polarized vertical patch antenna", *IEEE Transactions on Antennas and Propagation,* Vol. 54, No.4, pp. 1332-1335, 2006.

[6] N. Misran, et al., "Design and Development of Broadband Inverted E-shaped Patch Microstrip Array", *American Journal of Applied Sciences*, Vol.5, No.4, pp. 427-434, 2008.

[7] J. Kennedy and R. Eberhart, "Particle swarm optimization" in *Proceedings of the International Joint Conference on Neural networks, Perth. Australia,* Vol. 4, pp. 1942 – 1948, 1995.

[8] R.C. Eberhart and Y. Shi, "Particle swarm optimization: developments, applications, and resources", *Proc 2001 Conference Evolutionary Computing*, Vol. 1, pp.81–86, 2001.

[9] D.W. Boeringer and D.H. Werner, "Particle swarms optimization versus genetic algorithms for phased array synthesis", *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 3, pp.771–779, 2004.

[10] N B. Jin Y Rahmat-Samii,"Parallel particle swarm optimization and finite-difference time-domain (PSO/FDTD) algorithm for multiband and wide-band patch antenna designs" *IEEE Transactions on Antennas and Propagation*, Vol. 53, No. 11, pp. 3459-3468, 2005.

[11] Shi Y. and Eberhart. R.C, "A modified Particle swarm optimizer," *Proceedings of the IEEE International Conference on Evolutionary Computation.*, IEEE Press, Piscataway, NJ, pp. 69-73, 1998.

[12] J. Robinson and Y. Rahmat-Samii, "Particle swarm optimization in electromagnetic", *IEEE Transactions on Antennas Propagation*, Vol. 52, No. 2, pp. 397.407, 2004.

[13] X.F Liu et al, "Design of a Low –Profile Modified U Slot Microstrip Antenna Using PSO Based on IE3D", *Proceedings of Microwave and Optical Technology Letters*, Vol. 49, No. 5, pp. 1111-1114, 2007.

[14] Johnson, J. M., & V. Rahmat-Samii, "Genetic algorithms in engineering electromagnetic", *IEEE in Antennas and Propagation Magazine*, Vol. 39, No. 4, pp.7–21, 1997.

[15] Zeland Software Inc., "IE3D Electromagnetic Simulation and Optimization Package, Version 14.0", *Zeland Software Inc*., Fremont, CA, 2003.

[16] A. Hoorfar, "Evolutionary Programming in Electromagnetics Optimization: A review" *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 3, pp. 523-537, 2007.

[17] N.Jin & Y Rahmat-Samii, "Particle Swarm Optimization of miniaturized quadrature reflection phase structure for low-profile antenna application", *IEEE AP-S. Symposium Antennas and Propagation*, Vol. 2B, pp. 255-258, 2005.

[18] S K Behera and Y Choukiker, "Design and Optimization of Dual Band Microstrip Antenna Using Particle Swarm Optimization Technique", *Journal of Infrared, Millimeter, and Terahertz Waves*, ISSN 1866-6892,Vol. 31, No. 11, pp. 1346-1354, 2010.