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Optimization of Planar Antenna for ISM Band Using Particle Swarm Optimization Technique

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***Abstract*— An Inset fed E-Shape microstrip Patch Antenna has been developed and simulated for operation of Industrial, Scientific and Medical (ISM) band (2.40-2.52 GHz). The patch antenna is simulated 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 is working in ISM frequency band. These bands include the designated frequency bands of wireless standards IEEE 802.11, 802.11b, 802.15.2 and Bluetooth. The antenna exhibits good radiation characteristics and moderate gain in the entire operating band.**

***Index terms*: ISM Band, IE3D, Inset fed, Microstrip Patch antenna, PSO.**

I. 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 structure [1-8]. Recent advancements in wireless technology and significant growth in consumer demands have significantly increased the popularity of wireless networks. In order to regulate the interaction of different devices in such wireless networks, Bluetooth have been developed and currently being adopted in different countries [9, 10].

Many electromagnetic design tasks involve complex optimization problems, characterized by several competing design specifications and constraints, which cannot be solved without the aid of robust and efficient optimization algorithms.
In recent years, many Electromagnetic simulation software is available for designing of Microstrip antennae. Among them, the one of the powerful electromagnetic simulation software is IE3D [11]. Besides the optimization schemes viz. Random optimizer, Powell optimizer, Adaptive optimizer & Genetic optimizer available in IE3D®TM, there are several other optimization techniques available such as (i) Particle swarm optimization (PSO) (ii) Genetic Algorithm (iii) Simulated annealing etc [12-16].

The Particle Swarm Optimization (PSO) algorithm is very suitable and relatively simple method for optimization of electromagnetic problems [17]. This technique is simpler than the GA and has been successfully applied to a variety of fields. Especially, the PSO used in conjunction with the numerical electromagnetic solver and is found to be a revolutionary new approach to antenna design and optimization. The PSO is an iterative optimization procedure, which is based on the processes of ―movement" and ―intelligence" in an evolutionary system, it leads ultimately to the closest approximation to the antenna specification with minimal foresight or preconditioning on the part of the designer. The immense power of the technique is its ability to satisfy a performance criterion without any prior knowledge of candidate‘s configurations, and the facility for finding the global optimum result.

In this article, we will examine the use of a PSO to search a E-shape Microstrip patch antenna with optimal ISM band operation as well as suitable for wireless local area network (WLAN), Bluetooth applications. During the approach, the geometry parameters including the dimensions of the E-shape microstrip patch antenna and the slits, the sizes of the inset fed are all left as the design variables for manipulation by the PSO. In addition, the IE3D$^{®TM}$ (method of moments based software by Zeland) was used to predict the performance of antenna design in conjunction with the PSO. Details of the antenna design are described, and prototypes of the PSO optimized antenna for ISM band are proposed. This Antenna covers ISM band ranging from 2.40-2.52 GHz with VSWR 2:1 and -10 dB bandwidth of 121.9 MHz.

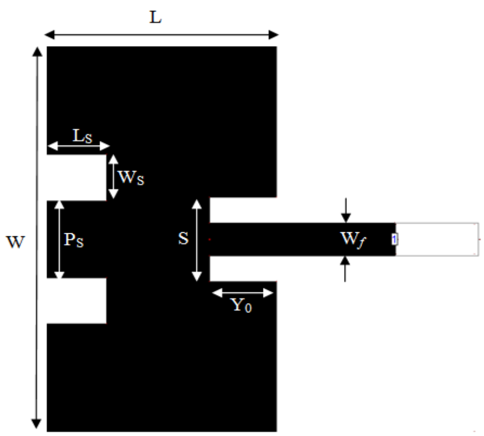


Fig. 1. Geometry of proposed antenna

II. Design Of Microstrip Patch Antenna

A. Geometry

The geometry of E-shape Microstrip patch antenna using Inset-fed for achieving ISM band operation is shown in Fig. 1. The basic of the antenna structure is chosen to be a rectangular patch has dimensions of width (W) and length (L). It is constructed on a substrate with relative permittivity (ε_r) of 2.55 and thickness (h) of 2 mm. The resonant frequency of the Microstrip antenna is around 2.45 GHz. A 50 Ω transmission line is fed by Inset feding method (>L/2).The inset thickness *(*W_f), inset depth (Y_0), Span (S) are the important parameters for controlling the frequency and return loss. Two parallel slots of length (Ls), width (Ws*)* and distance between the slots (Ps) are incorporated into the patch.

B. Design Model

IE3D$^{®TM}$ Electromagnetic simulation software is based on method of moment (MOM) for solving the structure of general shape. Different Optimization techniques are available in IE3D$^{®TM}$ viz. Random optimizer, Powell optimizer, Adaptive optimizer & Genetic optimizer. The variables for optimization are defined by IE3D$^{®TM}$ and controlled by its direction and bounds. However, the variables can only be connected with another by fixed rate. More complicated relation between variables cannot be set in IE3D$^{®TM}$. The width and the span of patch are placed on vertical position on patch and may cause overlap problems in IE3D$^{®TM}$ optimization. In this article, the parameters of the rectangular Microstrip patch antenna are obtained by combining particle swarm optimization with IE3D$^{®TM}$.

C. Particle Swarm Optimization

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 behaviour of bird flocking. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA).

PSO developed by Kennedy and Eberhart 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 neighbourhood. The evolution of particles, guided only by the best solution, tends to be regulated by behaviour of the neighbours.

The antenna parameters to be optimized (e.g. length and width) shall form the position of the particle. A set of such positions shall be taken initially. Fitness of each position shall be evaluated based on an objective function. The objective function shall be 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. Based on the antenna characteristic, it can be single-objective (e.g. only the bandwidth of the antenna or only the directivity of the antenna etc) or multi-objective (e.g. bandwidth and directivity of the antenna taken together).

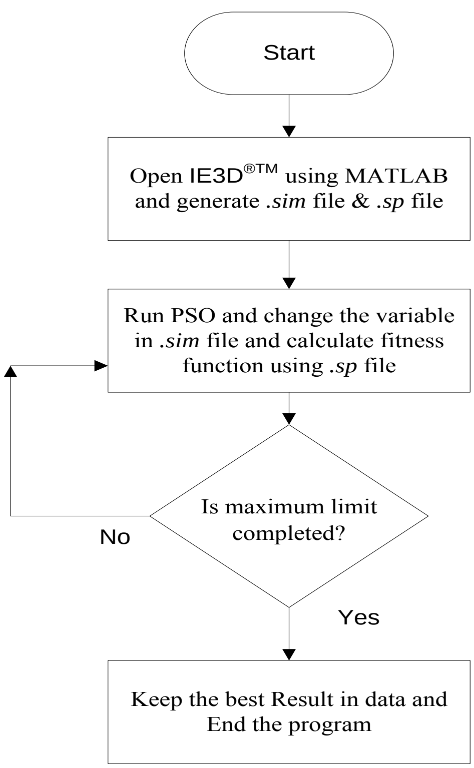


Fig. 2. Flow chart of IE3D®™ /PSO

In the initial stage PSO is developed for single objective optimization. The particles are generated using MATLAB®™ programming and linked to IE3D®™ to obtain data for optimization.

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*.

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

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

In the above, $Vi\ (t)$ is the velocity of the particle in the i^{th} dimension; $X_i\ (t)$ is the particle‘s coordinate in the i^{th} 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 and C_2 are two random constants usually fixed to be 2.0, η_1 and 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 i^{th} particle‘s position which attains its personal best fitness value while

X_{gbest} records the position which attains its global best fitness value.

PSO algorithm uses fitness evaluation to represent how well a solution satisfies the design parameter. Therefore the fitness is calculated by:

$$F = \sum_{i=o}^{N} W_i f_i \qquad 3$$

Where N is the number of fitness factor, f_i is the value of i^{th} fitness factor and W_i is the weighting coefficient.

Table I:Design Parameter Of Patch Antenna

(ε_r=2.55, h=2) *All dimensions are in mm*

Bound	L	W	Y_0	S	Ls	Ws	Ps
Low Bound	35	40	5	5	5	5	5
High Bound	45	70	20	15	15	10	20

The flow chart of interfacing between IE3D®TM-PSO is shown in Fig. 2. The variables for optimization defined by IE3D 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 PSO program, optimization for complicated structure can be performed. Fitness function value is obtained by calculating the simulated results saved in the *.sp* file.

Table II: Optimized parameter of microstrip patch antenna

(ε_r=2.55, h=2) *All dimensions are in mm*

L	W	Y0	S	Ls	Ws	Ps
37.4	66.52	11.27	14.54	10.23	7.67	14.5

D. Design Parameter

In this article, the rectangular Microstrip patch antenna for ISM band with resonant frequency at 2.45 GHz is designed. The design parameters for the antenna are listed in Table I and optimized parameters of the antenna are listed in Table II. The number of particle set to be 10 and number of iteration set to be 1000. The fitness function is given by.

$$Fitness = \min\left(S_{11n}^2\right)_{(2.45GHz)}$$

Where ‗n' is the sample point in the return loss versus frequency.
The simulation took 4 hours (approx) on a HP mobile workstation with 2 GB RAM.

III. Result And Discussion

A. Fitness Function Characteristics

Fig. 3 reveals the progress of the PSO routine as a function of the number of iteration. It shows actual data from the PSO, which demonstrate this phenomenon for a one-dimensional (1-D) optimization of a fitness function. The optimal E-shape Inset-fed microstrip patch antenna for ISM band has reached after 600 iterations. The *gbest* (global best) value of 0 is obtained by the fitness function which is satisfied the frequency band of proposed microstrip patch antenna.

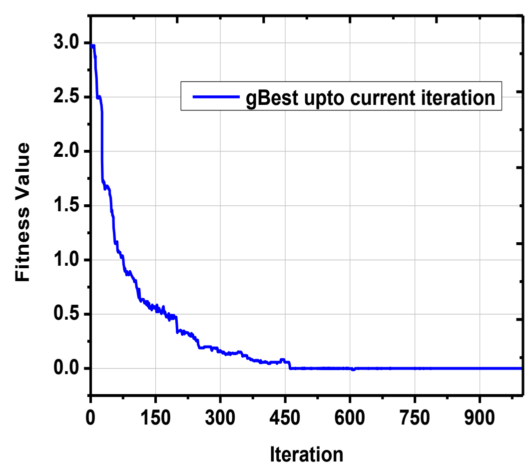


Fig. 3. Fitness of the best antenna in each iteration during the IE3D®TM-PSO process

B. Return Loss Characteristics

The parameters of rectangular microstrip patch antenna in ISM band are obtained by IE3D®TM-

PSO method. The optimized parameters are listed in Table II. The optimized antenna is simulated using IE3D®TM (version 14.0) available in our laboratory. The return loss of -40dB at frequency 2.42 GHz is obtained and is shown in Fig. 4.The bandwidth of 121.9 MHz (<-10 dB) obtained ranging from 2.4-2.52 GHz which is suitable for ISM band.

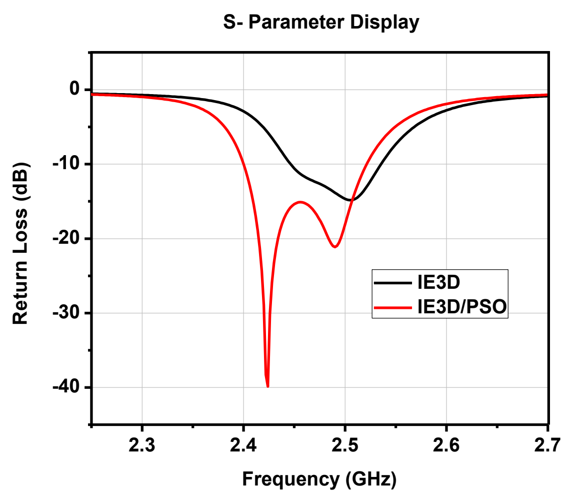


Fig. 4. Return loss against frequency (ISM Band) for proposed antenna

C. Radiation Pattern Characteristics

Radiation pattern characteristics of proposed optimized antenna is shown in Fig. 5 and Fig. 6 at 2.4 GHz and 2.52 GHz in the broad side direction at V=0° and V=90°. In addition, very monopole like radiation pattern with omnidirectional radiation in Elevation plane is observed.

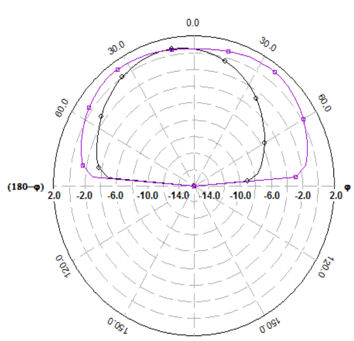


Fig. 5. Radiation pattern for antenna studied at Fig. 3 at frequency 2.4 GHz

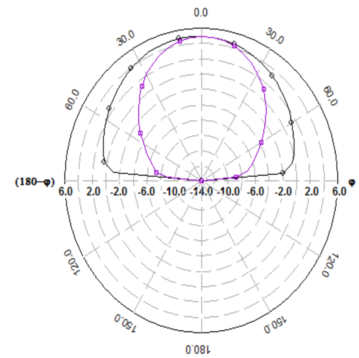


Fig. 6. Radiation pattern for antenna studied at Fig. 3 at frequency 2.52 GHz

D. Antenna Performance (Gain)

When the antenna is used for particular frequency band application, the impedance mismatch must be taken in to account for defining its characteristics. Especially, while calculating antenna gain, IE3D®TM-PSO method is used to compute the gain of the proposed antenna as shown in Fig. 7. The maximum realized gain at the range of 1-5 dBi is obtained for the antenna.

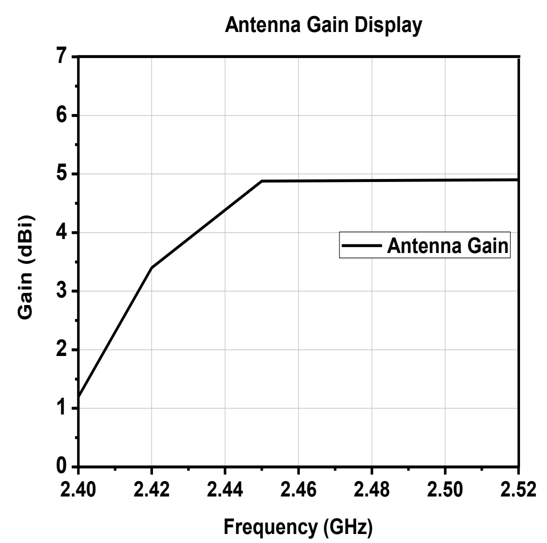
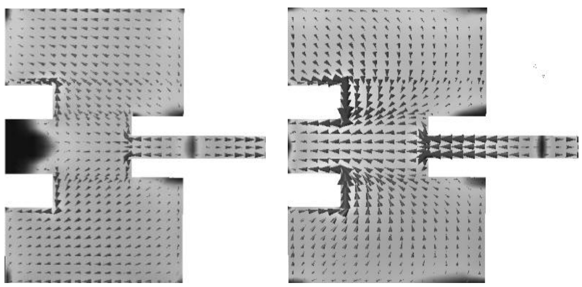


Fig.7. Peak gain of the proposed antenna for ISM band

E. Surface Current Distribution Characteristics

The excited surface current distribution, obtained from the IE3D®TM-PSO simulation, of the E-shape microstrip patch antenna. Fig. 8 (a) and (b) shows the surface current distribution at 2.4GHz and 2.52 GHz. It is clear that both the frequencies have very similar surface current distributions on the Inset-fed patch. This characteristic agrees with the radiation patterns characteristics of both frequencies shown in Fig 5 and 6. Moreover, it has also been found that in this design the surface current on the Inset-fed patch is strong and dominates the main radiation performance of the antenna. This results in a very linear polarization pattern and also agrees with the simulated radiation pattern results.



(a) (b)

Fig.8. (a) Surface current distributions at 2.4 GHz frequency. (b). Surface current distributions at 2.52 GHz frequency

IV. CONCLUSION

The design and optimization of Inset-fed E-shape Microstrip patch antenna is presented for ISM band. The antenna is developed by combining the efficient evolutionary optimization method (PSO) with a standard electromagnetic simulator (IE3D$^{®TM}$). The simulation results show that the proposed antenna can offer good performance for ISM band ranging from 2.40-2.52 GHz. The antenna achieved -10dB impedance bandwidth of 121.9 MHz. This method can also be effectively used in the design of various complex microwave and millimeter-wave circuits.

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