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# Design and Optimization of Dual Band Microstrip Antenna using Particle Swarm Optimization Technique

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**Abstract** Dual-frequency operation of antenna has become a necessity for many applications in recent wireless communication systems, such as GPS, GSM services each operating at two different frequency bands. A new technique to achieve dual band operation from different types of microstrip antennas is presented here. An evolutionary design process using a particle swarm optimization (PSO) algorithm in conjunction with the method of moments (MoM) is employed effectively to obtain the geometric parameters of the antenna performance. In this article a PSO based on IE3D®TM method is used to design dual band inset feed microstrip antenna. Maximum return loss is obtained at 2.4GHz is -43.95dB and at 3.08GHz is -27.4dB. Its bandwidth, of 33.54MHz, ranges from 2.38355GHz to 2.41709GHz. Simulated and experimental results of the antenna are discussed.

**Keywords** PSO, IE3D®TM electromagnetic simulator, microstrip antennas, dual band antennas

## 1 Introduction

Use of patch antennae is increasing in wireless applications due to their properties like low profile, lightweight and compatibility with monolithic microwave integrated circuits (MMICs) [1, 2]. They are extremely compatible for embedded antenna in wireless devices such as Cellular phones, satellite links & wireless local networks (WLANs) as they can easily be integrated in MICs. In applications needing increased bandwidth for operation at two separated sub-bands, a valid alternative to the broadening of total bandwidth is dual frequency patch antenna. Indeed, the optimal antenna for a specific application is one that ensures the matching of the bandwidth of the transmitted and/or the received signal. Dual frequency antennae exhibit a dual-resonant behaviour in a single radiating structure.

The design of dual band antennas has been a subject of intensive study during six decades [1-6]. The technique of embedding slots inside a microstrip patch to produce a dual band frequency response with both frequencies having the same polarization sense has been widely reported [3-6]. $TM_{01}$& $TM_{03}$ modes are used to produce a large frequency ratio [3, 4]. $TM_{0\delta}$ mode is created in between $TM_{01}$& $TM_{03}$ modes by embedding slots along the non-radiating patch edges [5,6]. It is difficult to achieve a suitable impedance match at both the frequencies. For such a design, the feed position is required to produce optimum impedance matching at both frequencies. This article proposes a new design for a dual frequency rectangular patch antenna with reduced feed position sensitivity.

## 2 Design of Dual Band Antenna

The dual band antenna design is presented in this section.It is well known that cutting slots in a rectangular patch antenna introduces additional resonances and dual band features. However, the geometrical parameters should be carefully determined to operate the antenna at desired frequencies. The goal of optimization is to determine the six geometrical parameters in Fig. 1, in order to achieve a dual band antenna operating at 2.4GHz and 3.1GHz. The proposed structure consists of a rectangular patch dimension W×L using inset planar feed on a dielectric substrate having relative permittivity ($\varepsilon_r$) of 2.4 and height (h) of 1.58mm.The antenna is designed and simulated using IE3D®TM software [7].

### 2.1 Geometry of the Patch

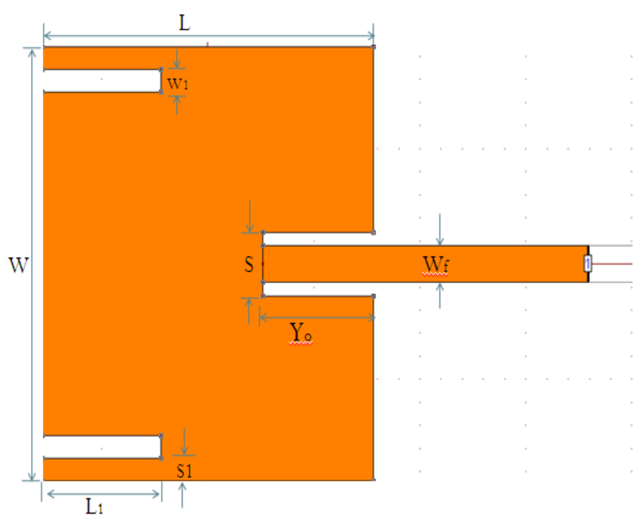


**Fig 1** Geometry of inset-fed dual-band patch antenna

The antenna (Fig. 1) is a rectangular patch of dimension W × L with two slots on one of the radiating edges. It is excited using an inset microstrip feed. The patch design consists of two stages. The first stage involves the creation of an additional $TM_{0\delta}$ resonant mode at a resonant frequency above that of the fundamental $TM_{01}$ mode with the same polarization sense. The second stage brings the input impedance of both modes towards 50Ω at their respective resonances through the use of an inset feed. The designed antenna is a dual band rectangular planar feed microstrip antenna. In microstrip patch antenna, the feed line impedance at resonance is mostly set to 50**Ω**, whereas at the edge of the patch, the impedance is a 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 performances. The input impedance of the rectangular microstrip patch antenna decides the matching between the feed line and the patch. According to the transmission line theory, the resistance of the patch varies as a cosine squared function along the length of the patch.

Since the operating frequencies of this resonant-type antenna are closely related to current path lengths in the patch, the six geometrical parameters in Figure 1, including the patch length *L*, the patch width *W*, the slot length $L_1$, the slot width $W_1$, the span S, and the feed position $Y_0$ are optimized using IE3D®™ /PSO. The parameters defined in IE3D®™ are generally controlled by boundary conditions and directions with fixed rate. In IE3D®™ simulator various optimization tools such as Powel, Random, Genetic and Adaptive are available. It has been observed that for any variation in optimization parameters, overlapping problems arise in the IE3D®™ simulation and the iterations terminate prematurely with an error. This error can be minimized by using the powerful optimization tool but IE3D®™ cannot deal directly with the external optimizer. Now a day, PSO has been used extensively in signal processing field to optimize multi-objective problems [8-10]. Therefore, a novel technique of designing is developed here 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). PSO developed by

Kennedy and Eberhart [8, 9] 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.

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 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).

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. The optimized antenna is then fabricated and experimental results are compared with the simulated results.

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 $p_{best}$ (personal best); and the location of highest fitness function discovered by the swarm is called $g_{best}$ (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 $p_{best}$ and $g_{best}$ as per the equation given in 1 & 2 [12-16].

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

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

In the above, $V_i$ (t) is the velocity of the particle in the $i^{th}$ 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, $C_1$& $C_2$ are two random constants usually fixed to be 2.0, $\eta_1$ & $\eta_2$ 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 among all [17-21].

## 3 Method of Design and Optimization:

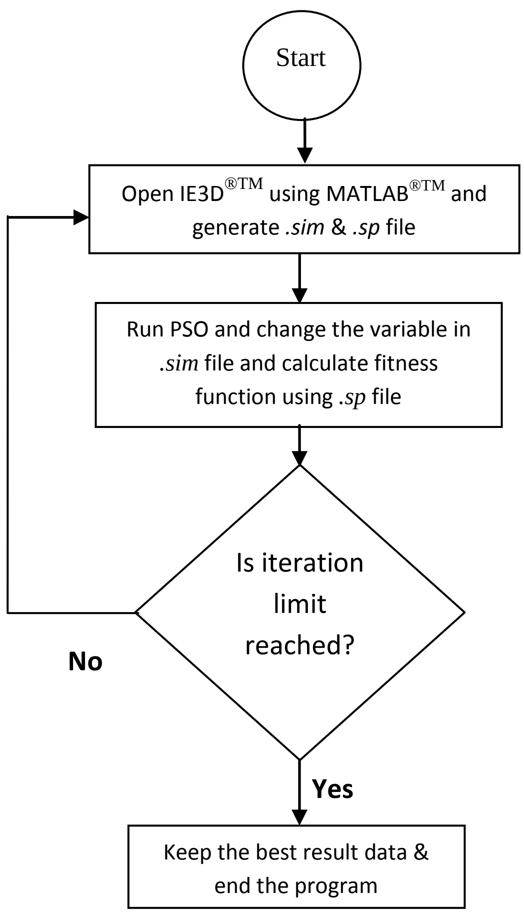


**Fig. 2** Flow chart of IE3D®TM /PSO

Table I: *Design parameters of microstrip patch antenna ($\varepsilon_r$=2.4, h=1.58 mm)*

*(All dimension in mm)*

| Bounds | Length | Width | Inset Depth | Slot length | Slot width | Span |
|---|---|---|---|---|---|---|
| Lower | 35 | 40 | 10 | 10 | 0.5 | 0 |
| Higher | 45 | 50 | 18 | 18 | 2.5 | 10 |

Table II: *Optimization parameters of microstrip patch antenna using IE3D®TM /PSO ($\varepsilon_r$=2.4, h=1.58mm)*

*(All dimension in mm)*

| Length | Width | Inset Depth | Slot length | Slot width | Span |
|---|---|---|---|---|---|
| 39.6226 | 49.000 | 13.2726 | 14.310 | 1.400 | 5.672 |

The design method of interfacing between IE3D®TM and PSO is explained in a flow chart is 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 PSO program, an optimization for complicated structure can be performed. Fitness function value is obtained by calculating the simulated results saved in the *.sp* file. The optimization is executed using a 10-agent swarm for 1000 iterations. The antenna is designed at 2.4 GHz frequency and the fitness function is defined as:

$$Fitness\ Function = \left\{1 - \left[0.5\frac{S_{11}(2.4)}{-30} + 0.5\frac{S_{11}(3.1)}{-25} + \sum_{i=1}^{2} G_i\right]\right\} \qquad (3)$$

$$G_i = \begin{cases} 1, & if\, S_{11}(f_i) \le -10dB \\ 0, & if\, S_{11}(f_i) > -10dB \end{cases} \qquad (4)$$

$i = 1\ and\ 2\ for\ 2.4\ GHz\ and\ 3.1\ GHz\ frequency$

**4 Simulation and Experimental Results**

The simulation is performed using Zealand's **IE3D®TM EM simulator (Version 14.0).** The simulated results of antenna performances such as return loss, VSWR, convergence curve and radiation patterns are given in Figs. 3, 4, 5, 6 and 7 respectively. High return losses are observed at

2.4 GHz (-43.95dB) and at 3.08 GHz (-27.41dB). The plots of radiation patterns in Polar form are shown in Figs. 7 and 8. A 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 $78^0$ at 2.4 GHZ are observed. In Fig. 5 both the return losses at 2.4 GHz & 3.1GHz and fitness of the best design antenna in iteration are shown. The dual band operation has been optimized in 82 iterations and thereafter the performance remains constant. During simulation the CPU time taken by a HP Pentium-IV system with 3GB RAM is around 8 Hours.

A prototype of proposed patch antenna with operating frequency 2.4 GHz was fabricated on Ultralam® 2000 substrate with Dielectric constant($\varepsilon_r$) = 2.4 and thickness of 1.58mm. The return loss and VSWR of fabricated antenna were measured on an Agilent Technologies®™ (Model: E5071C) Network Analyzer. It is observed that the antenna has two resonant frequencies at 2.4GHz and 3.1 GHz that agree well with the simulation results and good return loss has been achieved. VSWR is also maintained below 2 at 2.4 GHz and 3.1GHz.

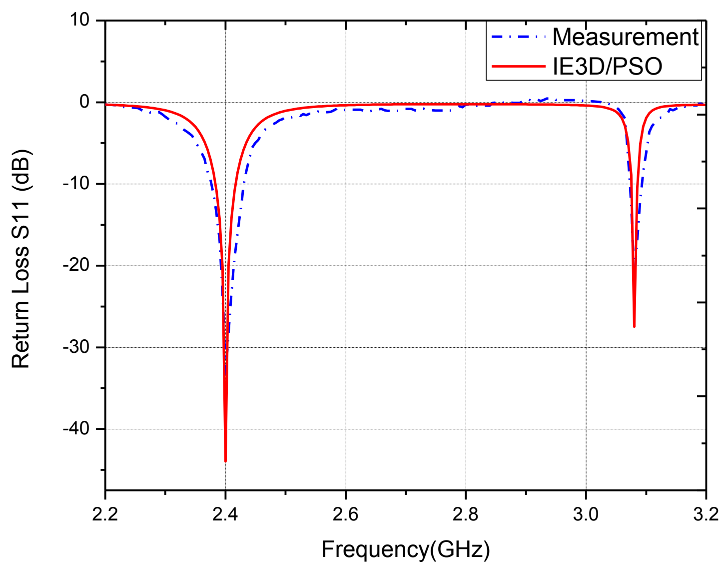


**Fig 3** Return loss using IE3D®™ / PSO and Measured data.

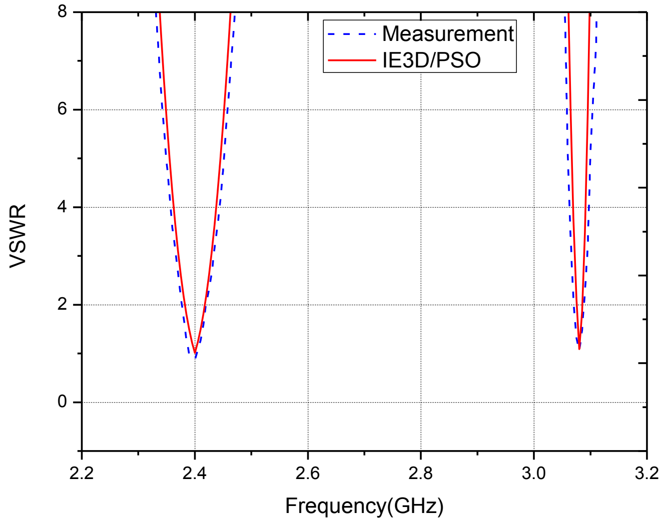


**Fig 4** VSWR using IE3D®TM / PSO and Measured data.

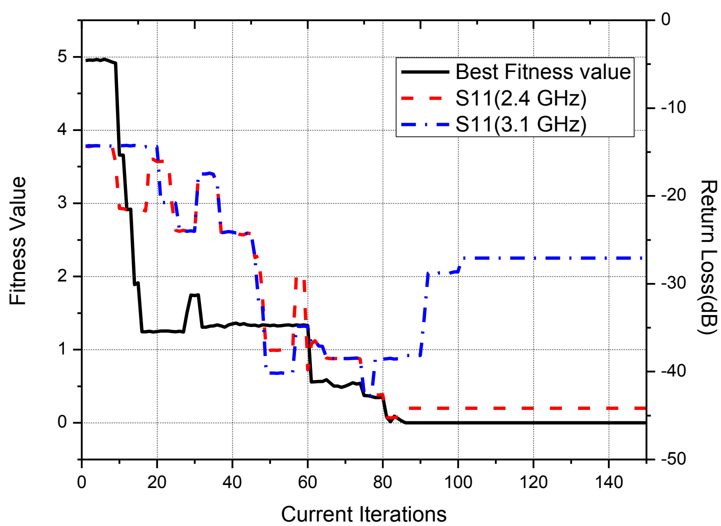


**Fig 5** Convergence curves of IE3D®TM /PSO optimization

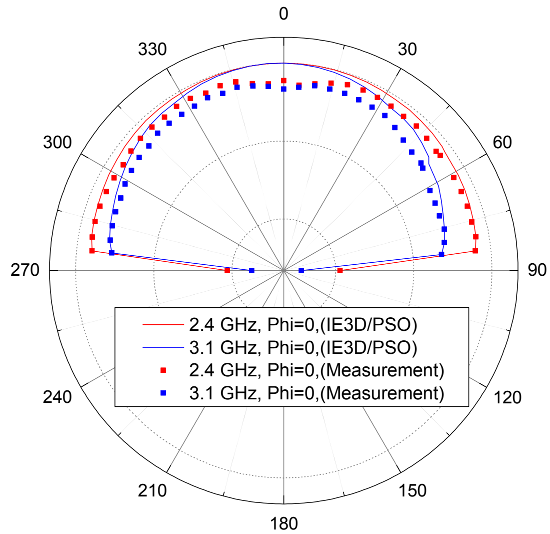


**Fig 6** E-plane pattern of IE3D®TM /PSO and measured data at 2.4GHz & 3.1 GHz

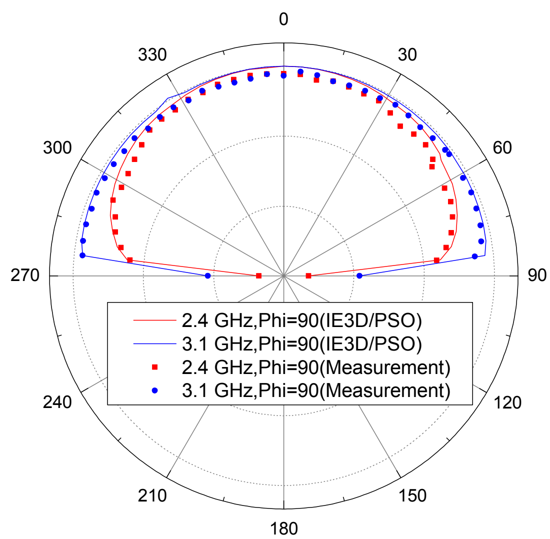


**Fig 7** H-plane patterns of IE3D®TM /measured data at 2.4GHz & 3.1 GHz

## 6 Conclusion

The design, optimization and practical implementation of a novel dual-frequency antenna has been presented and discussed. It has been shown that with correct selection of slot dimensions and positions, a dual frequency response can be achieved. This paper discusses the optimizations of return loss and radiation pattern, while the flexibility in defining the fitness function allows PSO to address other design requirements. It is observed that as a stochastic global optimizer, PSO is particularly suitable for antenna optimizations which are in general extremely nonlinear and multimodal. Both simulation and measurement results of PSO optimized antennas are presented in order to validate the capability of PSO in producing a useful and practical design.It shows that the IE3D®TM /PSO method used in this article is an efficient method for antenna design and optimization.


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