Optimal Rectangular Microstrip Antenna with and without Air Gaps Design by Means of Particle Swarm Optimization and Vortex Search Algorithm

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Abstract: In this paper, Particle Swarm Optimization and Vortex Search Algorithm are applied to design desired characteristics of rectangular microstrip antenna with and without air gaps. The proposed artificial intelligence algorithms are inspired from natural events or behavior of living things in nature. Resonance frequency and return loss of microstrip antenna are dependence with design parameters. The computed results for dielectric substrate's height is tuned by Particle Swarm Optimization and Vortex Search Algorithm for optimal design.

Key words: Optimization, particle swarm optimization, rectangular microstrip antenna, vortex search algorithm, with and without air gap.

1. Introduction

Microstrip antenna applications have increased consistently with last years. It has several advantages such as small size, compatibility with planar and non-planar surfaces, usage of modern print-circuit application, low cost etc. Microstrip patch antenna has been made to integrate successfully in GSM and satellite communication applications. Additionally, it is used in aircraft, medical, missiles and military communication. Since microstrip antenna has narrow bandwidth, it is important to compute the resonant frequency accurately [1]-[5].

Microstrip antennas idea emerged in 1953 and although it received a patent in 1955 but began to attract interest starting in the 1970s. Microstrip antennas on the very thin ground plane consists of quite small height than wavelength placed a metal strip on the dielectric substrate. For the transverse radiation, maximum of radiation pattern is set to be perpendicular to patch plane. At the same time, longitudinal radiation can be performed with a suitable electromagnetic mode selection.

Narrow bandwidth is a major disadvantages for microstrip antenna. The best method is multi dielectric layer materials applied on microstrip antenna in order to increase bandwidth. This design has better dual-band performance than conventional single layer antenna [6]. Works on microstrip antenna with an air gap was started by Lee and Dhale and has been investigated for circular patch geometry. This idea of leaving an adjustable air gap width between the substrate and the ground plane has been tried to search for solutions to the existing antenna problem. A slight increase in the resonant frequency of the air gaps in design might cause a decrease in the effective dielectric properties. The resonance frequency can be tuned by changing the air gap width. Bandwidth is partly increased by the reduction of the equivalent dielectric constant and increase in the equivalent dielectric substrate's height [7]. In addition, a second air gap designs allow the advantage of reduced bandwidth dual band operation.

2. Theory

2.1. Basic Geometry without Air Gap

Microstrip antennas are often referred to as the patch antenna. Radiating elements and feed lines are usually made by soldering on the dielectric substrate material as Fig. 1. There are many substrate materials whose dielectric constant is in range of 2.2< $\mathcal{E}_r$<10 for patch design. The most preferred dielectric constants for a good antenna performance is at the lower values of the above range. Despite the limitations of radiation fields, these materials provide better efficieny, higher bandwidth and larger patch sizes.

Patch geometry can have square, rectangular, dipole, circular, elliptical, triangular or can any other type of structure. Square, rectangular and circular patch geometries are quite common due to their simple analysis and production. Thickness of the metallic patch very less than the wave length ($t<<\lambda_0$) and on top of that $h<<\lambda_0$ or $0.003\lambda_0 \leq h \leq 0.005\lambda_0$ is suggested for selection of dielectric substrate's height [8].

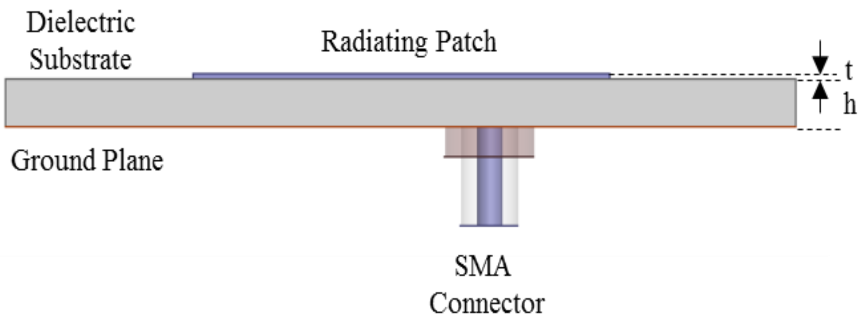

Fig. 1. Cross sectional view of a proposed patch antenna without air gap.

Distribution of electrical field on microstrip antenna is a function of L/h and $\mathcal{E}_r$. When L/h is smaller than 1, effect of electrical field on substrate decreases. Most electric field lines are inside substrate material and some lines partially within the air. Electric field lines are mainly located in the substrate as W/h>>1 and $\mathcal{E}_r$>>1. In this case, the electromagnetic field distributions on the physical size of the microstrip patch will have a larger electrical appearance. L can be usually chosen to be between $\lambda_0/3$ and $\lambda_0/2$ for rectangular patch structure. In microstrip antenna design is necessary to be consider the formula below:

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$\varepsilon_{reff} = \frac{\varepsilon_{req} + 1?}{2} + \frac{\varepsilon_{req} - ?}{2}\left(1 + \frac{10h}{W}\right)^{-0.5} \tag{2}$$

$$\frac{\Delta L?}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)?}{(\varepsilon_{reff} - 0.258)} + \frac{\left(\frac{W}{h} + 0.262\right)}{\left(\frac{W}{h} + 0.813\right)} \tag{3}$$

$$L_{reff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4}$$

$$L = L_{\text{reff}} - 2\Delta L \tag{5}$$

2.2. Geometry with Air Gap

The air gap used in the antenna geometry is possible to obtain dual band. However, the removal of the air gap in the antenna configuration is more useful for narrow bandwidth applications. In Fig. 2, the dielectric constant of the polyimide Quartz substrate material ($\mathcal{E}_r$=4) and tangent loss (t=0.0001) are used for the air gap design. SMA connector design is used to transfer energy from ground plane to patch [9]. Generally, air gap is between ground plane and dielectric substrate in conventional antenna with air gap design.

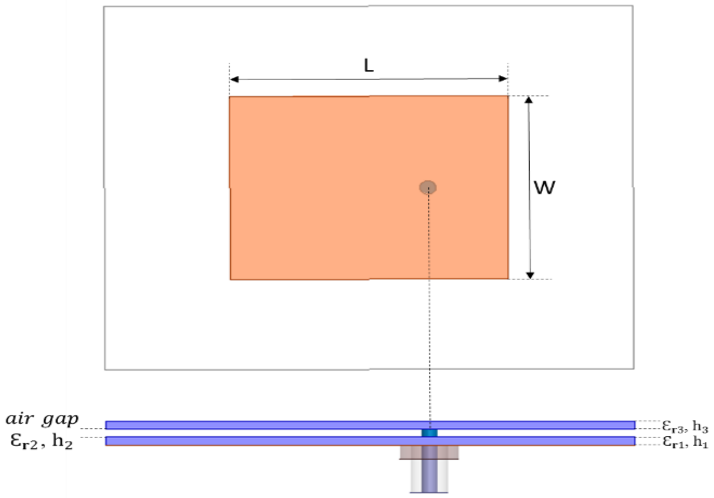

Fig. 2. Dimensions of rectangular microstrip antenna with air gap.

A rectangular microstrip antenna patch dimensions for multilayer with air gap design mentioned as thickness and dielectric constant each layers are h_1, h_2, h_3 and $\mathcal{E}_{r1}$, $\mathcal{E}_{r2}$, $\mathcal{E}_{r3}$. Multilayer microstrip antenna with air gap and equivalent dielectric constant layer is showed in Fig. 2.

3. Artificial Intelligence Algorithm

3.1. Particle Swarm Optimization

Particle Swarm Optimization (PSO) was firstly proposed by Eberhart and Kennedy in 1995 [10]. It has been developed on the behavior of the animal when they search for food sources. Even members of swarm has no information about food location, they have ability to find sources due to cognitive, social and exploratory policies of swarm [11]. Every member is assumed based on generally accepted expression as a particle. Each particles moves on the search space by means of change in velocity and location. Accordingly, optimum solution of function is found in d-dimensional workspace, searching process is started with initial position and velocity for d-dimensional vector particle.

Each particle in PSO algorithm represent a possible solution to the optimization problem. Swarm corresponds to population and particle represents individual similar to evolutionary computing paradigms. Particles strive to move around the optimum particles. Therefore, it is a search space where the information of location is required to share in each particles. The best exchanging location in swarm is called as "*gbest*". Other location sharing method between neighbors takes place at the local level. In this way, the local best particle is called "*lbest*" in case of sharing the knowledge about location. The biggest difference between two sharing methods is invention of local optimum. *lbest* has lower chance to converge into local optimum than *gbest* in later iteration.

$X_i(t)$ shows the position of the i th partcile at t time step in search space. t represents th discrete time steps. Particle position is varied by adding $V(t)$ velocity to actual position in Eq. 6.

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{6}$$

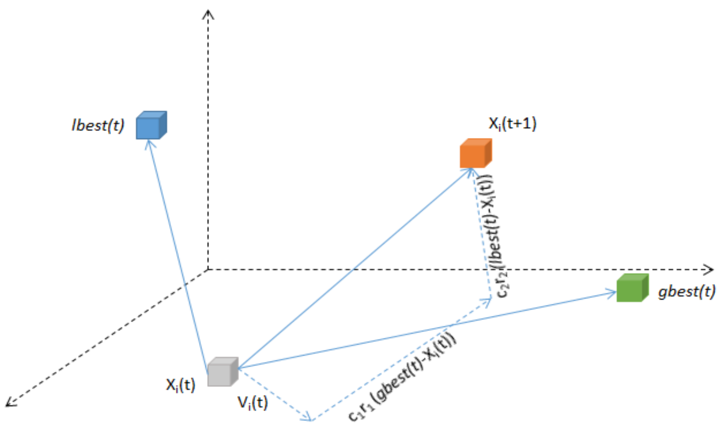

Fig. 3. The change in particle's velocity and position.

The velocity vector directs the optimization process and offers experimental information related to both particle and his neighbor. Each particle's neighborhood covers the entire swarm for *gbest*. Social network in *gbest* resembles star topology which is based on the particle velocity change in accordance with the information obtained from all particles in the swarm as Fig. 3. In this case, social information is the best position found by swarm. In the PSO, velocity of i th particle is updated by this formula:

$$V_i(t+1) = V_i(t) + c_1.r_1(lbest_i(t) - X_i(t)) + c_2.r_2.(gbest_i(t) - X_i(t)) \tag{7}$$

$V_i(t)$ is velocity of i th partcile at t time step. c_1 and c_2 are positive acceleration constant in order to scale the contribution of cognitive and social components. r_1 and r_2 are random distributed numbers in range of 0 and 1 for adding stochastic feature to PSO algorithm [12]. The best position "*lbest*" in minimization problems is updated by following formula:

$$lbest_i = \begin{cases} lbest_i, \; f(x_i(t+1)) \geq f(y_i(t)) \\ x_i(t+1), \; f(x_i(t+1)) < f(y_i(t)) \end{cases} \tag{8}$$

n_s is represents the total number of particles in swarm. *gbest* can be chosen from actual *lbest* values via Eq. 9:

$$gbest = \min\{ f(x_0(t), \ldots\ldots\ldots f(x_{ns}(t) \} \tag{9}$$

3.2. Vortex Search Algorithm

Many algorithms inspired by metaheuristic is used to solve problems of optimization in recent years. The proposed artificial intelligence algorithm is inspired from vortical flow of fluids and provide a good innovative result for numerical problems. A swirl pattern is mathematically modelled to find optimal solution in search space by using adaptive step reduction methods. Despite unguaranteed global minimum, they are widespread due to quick and easy to be implemented. Vortex search algorithm work as mixed fluid swirl pattern which is modelled like nested circle. To find center of the circle (μ_0):

$$\mu_0 = \frac{upLim + lowLim}{2} \tag{10}$$

upLim and *lowLim* are dx1 vectors to constrain boundary of solution in d dimensional search space [13]. A number of random solutions $C_t(s)$ are generated by using Gaussian distribution. $C_0(s)=\{s_1, s_2, s_3, \ldots, s_k\}$ is candidate solutions and *n* represents total number of solution set. σ_0 is initial standard deviation of distribution and can be formulated as Eq. 11:

$$\sigma_0 = \frac{\max\left(upLim\right) - \max(lowLim)?}{2} \tag{11}$$

The initial standard deviation (σ_0) of the distribution indicates the initial radius of epicycle. The best solution (s^i) is selected in $C_t(s)$. However, random solutions must be checked in valid boundary of problem before s^i is determined as:

$$s_k^i = \begin{cases} rand.(upLim^i - lowLim^i) + lowLim^i, s_k^i < lowLim^i \\ s_k^i, lowLim^i \le s_k^i \le upLim^i \\ rand.(upLim^i - lowLim^i) + lowLim^i, s_k^i > lowLim^i \end{cases} \tag{12}$$

For this purpose, the solutions that exceed the boundaries are transferred into the boundaries [14]. In the selection part, s^i in the each iteration compares with global best solution (*sbest*). If s^i is better than *sbest*, it assigns as the *sbest* which is assumed the center of next random solutions. For next iteration, candidate random solutions with gauss distribution are regenerated in accordance with decremential radius of inner circle. At the end of the algorithm, *sbest* is the best solution for the optimization problem.

The way of the radius reduction is very important for global search ability. On the other hand, local search ability is capable of finding global solution at the further steps. Inverse incomplete gamma function with chi-square distribution is strategy to reduce vortex radius as Eq. 13:

$$\delta(x,a) = \int_0^x e^{-t} t^{a-1} dt \quad a > 0 \tag{13}$$

a is shape parameter and bigger than zero. *x*>0 is a random variable. Also, complementary incomplete gamma function is represented in the following formulation:

$$\Gamma(x,a) = \int_0^\infty e^{-t} t^{a-1} dt \quad a > 0 \tag{14}$$

$\Gamma(x, a)$ is defined as 'the gamma function' to be proposed for calculation of incomplete gamma function [15]. MATLAB has several available tools for the gamma function (*gamma*), incomplete gamma function (*gammainc*) and inverse gamma function (*gammaincinv*). *a* is the shape parameter of gamma functions in [0,1] and can be calculated by using Eq. 14 at each iteration step:

$$a_t = a_0 - \frac{t}{MaxItr} \tag{15}$$

Changes in radius depending on the number of iteration is given in Eq. 16. The first half of process has weak locality when the radius changes linearly. In contrast, the algorithm has a strong locality in other half of process.

$$r_t = \sigma_0 .(1/x).gammaincinv(x, a_t) \tag{16}$$

4. Results

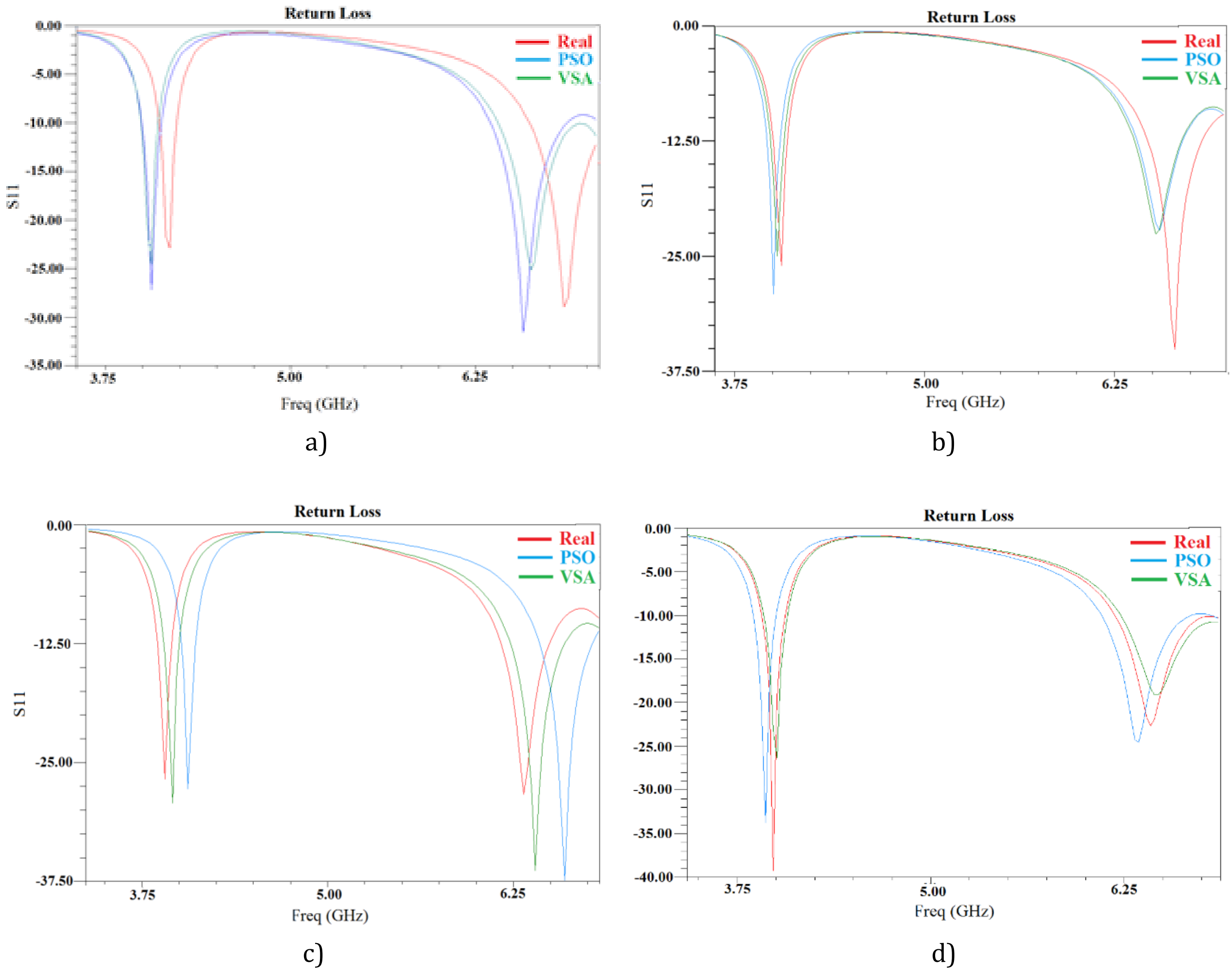

Fig. 4. Comparative HFSS results.

Rectangular microstrip antenna patches of dielectric material and air gap's heights are computed by using artificial intelligence algorithms. According to these results, the return loss of the antenna and the dual band frequencies was simulated in HFSS 13.0 program. Results show that there are significant difference between Particle Swarm Optimization (PSO) and Vortex Search Algorithm (VSA). Both of the algorithms can be reached the optimum solution quickly and correctly in Fig. 4. Accuracy may not have high rate due to nonlinear correlation between data sets.

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