Optimization of Z-Shape Microstrip Antenna with I-slot Using Discrete Particle Swarm Optimization (DPSO) Algorithm
Swarnaprava Sahoo, Laxmi Prasad Mishra, Mihir Narayan Mohanty*

Corresponding Author: Mihir Narayan Mohanty, mihir.n.mohanty@gmail.com, Ph: +919437056742
ITER, SOA University, Bhubaneswar, Odisha, India

Abstract

In this paper, discrete particle swarm optimization technique has been utilized in HFSS software for optimization of the Z-shape patch antenna with I-slot dimensions in order to achieve return loss, VSWR, directivity and gain. The designed antenna is to operate in Wi-Max / S-band and C-band satellite application with the center frequency at 3.5 GHz and 4.3 GHz and various important performance metrics of the patch antenna are analyzed for performing comparative analysis between un-optimized patch antenna and optimized patch design. The main point of the paper is to examine the suitability of discrete particle swarm optimization algorithm for antenna parameter optimization to achieve the better overall performance of the antenna. DPSO is general-purpose optimizer well suited for conducting search within a discrete search space.

Keywords: Microstrip antenna, Wi-Max, multi band antenna, dual band antenna, broadband antenna, optimization

* Corresponding author. Tel.: +91 9437056742; fax: +91 674 2351883.
E-mail address: mihir.n.mohanty@gmail.com
1. Introduction

The patch antennas are popular for their attractive features like: low profile, ease of fabrication, light weight and compatibility with Monolithic Microwave Integrated Circuits (MMICS). The patch antennas are used in satellite communication, microwave and wireless applications due to their planar structures and compactness [1-3]. The main disadvantage is an intrinsic limitation in bandwidth due to the resonant nature of the patch structure. The intensive research has been done to develop enhancement techniques of bandwidth for patch antenna [4-6]. The popular methods for bandwidth enhancement are increasing height of substrate and adding parasitic elements to the patch. In order to overcome the shortcomings of the microstrip antenna it is important to make an optimal design of antenna for best performance. In this case various existing optimization algorithms can come handy. Discrete particle swarm optimization algorithm is one of the global optimization algorithms has been widely used in the past by antenna designers [7-9] for the optimization of the patch size and shape in order to achieve better overall performance of the antenna.

To increase the bandwidth of antenna, including increase of the substrate thickness, the use of low dielectric substrate, the use of various impedance matching and feeding techniques, the use of multiple resonators and the use of slot antenna geometry, there are numerous and well known methods [10].

To achieve optimal gain, pattern performance, bandwidth, VSWR and so on subject to specified constraints, antenna design is a topic of great importance to electromagnetic and involves the selection of antenna physical parameters. In finding the optimum solution or unconstrained maxima or minima of continuous and differentiable functions, the classical optimization techniques are useful. These are analytical methods and make use of differential calculus in locating the optimum solution. The discrete particle optimization studies the general case in which the objective function or both contain conducting search within a discrete search space. The work has been performed by interfacing the discrete particle swarm optimization algorithm to Ansoft High Frequency System Simulator (HFSS).

The paper is organized as follows: section II presents a design approach for Z-shape patch antenna with I-slot, section III gives a brief about discrete particle swarm optimization algorithm and the steps used, in section IV simulation results are presented and finally in section V conclusion is drawn.

2. Antenna Design

The bandwidth of an antenna is mainly determined by the thickness, the nature of dielectric substrate and the geometry of the antenna. To expose the bandwidth matter in simple planar structures and to give a benchmark in terms of space and bandwidth, a rectangular patch has first been sized. The dimensions of the antenna can be deduced from analytical expressions [1],[4].

(a) Width of Patch: \[ W = \frac{\varepsilon_r}{2f_0 \sqrt{\varepsilon_r + 1}} \]
(b) Effective Dielectric Constant: \[ \varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{w} \right]^{-\frac{1}{2}} \]
(c) Due to fringing effects the change in dimension of length:
\[ \Delta L = 0.412 h \left( \frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.258} \right) \left( \frac{w}{h} + 0.264 \right) \left( \frac{w}{h} + 0.8 \right) \]
(d) Length of Patch: \[ L = \frac{\varepsilon_r}{2f_0 \sqrt{\varepsilon_{reff}}} - 2\Delta L \]

Where \( \varepsilon_r = \) Dielectric constant, \( h = \) Substrate thickness, \( f_0 = \) Resonant frequency

Increasing the width of this antenna is one of factors controlling its bandwidth. Nevertheless, it is very difficult to obtain a satisfactory result with a simple shape microstrip patch antenna. That is why we propose a Z-shape geometry with I-slot in order to widen the bandwidth of the antenna while retaining reasonable dimensions. This
geometry changes the distribution of surface current density generating multiple resonances.

The goal of designing antenna at 3.5 GHz, 4.3 GHz was to get better performance using optimization for Wi-Max / S-band & C-band Satellite application. The width of the rectangular patch antenna is usually chosen to be larger than the length of the patch to get higher bandwidth. To design patch antenna lower dielectric constant is used because in case of lower substrate dielectric constant, surface wave losses are more severe and dielectric and conductor losses are less severe. Table 1 shows the specifications for the proposed Z-shape patch antenna with I-slot.

Table 1. Optimized dimensions of proposed antenna

<table>
<thead>
<tr>
<th>Un-optimized dimensions of Z-shape patch antenna with I-slot parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>FR4- epoxy</td>
</tr>
<tr>
<td>Center frequency (f_c)</td>
<td>2.32 GHz, 3.62 GHz</td>
</tr>
<tr>
<td>Height of substrate (h)</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>Loss tangent</td>
<td>0.02</td>
</tr>
<tr>
<td>Dielectric constant (e_r)</td>
<td>4.4</td>
</tr>
<tr>
<td>Width of patch (W)</td>
<td>38.04 mm</td>
</tr>
<tr>
<td>Length of patch (L)</td>
<td>29.44 mm</td>
</tr>
<tr>
<td>Feed width (w_0)</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>y_0</td>
<td>5 mm</td>
</tr>
<tr>
<td>x_0</td>
<td>0.6 mm</td>
</tr>
<tr>
<td>L_3</td>
<td>30 mm</td>
</tr>
<tr>
<td>L_4</td>
<td>2.1 mm</td>
</tr>
<tr>
<td>L_5</td>
<td>4 mm</td>
</tr>
<tr>
<td>L_8</td>
<td>2 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Optimized dimensions of Z-shape patch antenna with I-slot parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_8</td>
<td>2.779 mm</td>
</tr>
<tr>
<td>L_5</td>
<td>2.317 mm</td>
</tr>
</tbody>
</table>

The most important design features of the patch are its width (W), length (L), width of transmission line and the length of the feeding line. The patch is fed by a 50 Ω inset feed. The geometry and configuration of Z-shape microstrip patch antenna with I-slot is shown in Fig. 1 and Fig. 2.

The proposed antenna is the Z - shape patch antenna with I- slot and after theoretical calculation for the rectangular microstrip antenna the optimization technique is used for the desired output. The parameters defined by HFSS are generally controlled by direction and bound with fixed rate. It has been observed that for any variations of the optimization parameters, overlapping problems arise in the HFSS simulation and the iterations terminate prematurely with an error. This error can be minimized by using the many powerful optimization tools.
3. **Discrete Particle Swarm Optimization (DPSO) Algorithm**

In the DPSO, the values of the particles are restricted to 0s and 1s (binary). They can be applied for solving problems with integer variables. Initially, in a DPSO algorithm, a pool of solutions is randomly generated. Each solution in the solution pool is represented by the position vector

\[ X_n = (x_{n1}, x_{n2}, x_{n3}, \ldots, x_{nd}) \]

where \( n \) denotes the number of solutions or the swarm size \((n = 1, 2, \ldots, N)\) and \( d \) represents the constituents (binary equivalents of variables) of the solution in space. The length of the binary solution \( X_n \) depends on the number of variables and binary bits allotted for each variable. Each solution is associated with a velocity vector denoted by

\[ V_n = (v_{n1}, v_{n2}, v_{n3}, \ldots, v_{nd}) \]

The dimensions of each velocity vector \( V_n \) are updated during every iteration \( t \) \((t = 1, 2, \ldots, T)\) using Eq. (1).

\[ v_{nd}^{t+1} = \omega v_{nd}^t + \theta_1 (b_{nd}^t - x_{nd}^t) + \theta_2 (g_{nd}^t - x_{nd}^t) \quad (1) \]

The notations \( g_{nd} \) and \( b_{nd} \) represent the global best and the local best positions attained by the constituent particles, respectively. The symbol \( \omega \) denotes the weight of inertia, which is a constant. The inertia factor represents the belief on the previous velocity. The learning factors \( \theta_1 \) and \( \theta_2 \) are constants and their values indicate the importance given for one’s own experience (local best) and the others experience (global best) in the swarm. Eqs. (2) and (3) are used for finding the new position of \( x_{nd} \) \((0 \text{ or } 1)\). A random variable \((r)\) is generated uniformly between the values 0 and 1. If \( r \) is less than the sigmoid function of \( v_{nd} \) (Eq. (3)), the new position of \( x_{nd} \) will be 1 else it will be 0. This could be understood from Eq. (2).

\[ x_{nd}^{t+1} = \begin{cases} 1, & \text{if } r < S(v_{nd}^{t+1}) \\ 0, & \text{otherwise} \end{cases} \quad (2) \]

A swarm of size \( N \) is created and iterated for \( T \) iterations following the above mentioned procedure every time to get the optimal/near optimal solution.

To design Z-shape patch antenna with I-slot, the illustration for the antenna parameter design based on the optimization technique is given as follows:

**Step-1**
Enter the center frequency, dielectric constant and thickness of substrate in patch calculator programmed by MATLAB.

**Step-2**
Use the outputs \((W, L)\) where \( L \) and \( W \) represent the length and width of the patch respectively for designing Z-shape patch antenna with I-slot in HFSS.

**Step-3**
Analyze the performance of the proposed patch antenna designed in terms of return loss.

**Step-4**
If the return loss is better than -20dB, then the proposed patch antenna is optimized otherwise go to Step-3.

First we calculate the antenna parameters that we analyze its performance, if the results are not satisfied we use discrete particle swarm optimization. The optimization is terminated when criteria is met. After ten iterations, the discrete particle swarm optimizer found the following optimal values for the parameters:

\[ L_6 = 7.6153 \text{ mm}, \quad L_8 = 2.779 \text{ mm}, \quad L_5 = 2.317 \text{ mm} \quad (\text{Fig. 1 and Table 1}) \]

4. **Simulation Results**

The Z-shape patch antenna resonates at the frequencies and are related to the dimensions \((L_1, L_2 \text{ and } L_6, L_7)\). These
dimensions are linked by the fact that the single excitation point must have matched impedance (50Ω) with the two resonant frequencies. Bringing closer these two resonant frequency is possible when we inset an I-shape slot in the middle of the Z-shape as seen in Fig. 1.

Rectangular Patch antenna has been designed in HFSS software and various important performance metrics are measured to analyze the performance of the designed Z-shape patch antenna with I-slot antenna (Fig.1). Now the Z-shape patch antenna with I-slot has been optimized to get the best possible results in all the possible ways and final results are presented in this section.

Return Loss: For better performance at resonance frequency the return loss should be minimal. The return loss plot for the designed Z-shaped patch antenna with I-slot is shown in Fig. 3.

The optimized Z-shape patch antenna with I-slot exhibits return loss of -19.4077 dB at 3.5 GHz and -19.5182 dB at 4.3 GHz. Where as the return loss plot of the un-optimized Z-shape patch antenna with I-slot is -18.88 dB at 3.5 GHz and -16.42 dB at 4.3 GHz.

Discrete particle swarm optimization 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 Z-shape patch with I-slot dimensions in order to achieve the desired goal.

VSWR: VSWR variation with frequency of the optimized and un-optimized Z-shape patch antenna with I-slot is shown in Fig. 4.
Fig. 4. VSWR Vs frequency plot of optimized and un-optimized Z-shape patch antenna with I-slot

From this plot it is clear that the un-optimized Z-shape patch antenna with I-slot has VSWR of 1.25 and 1.35 at 3.5 and 4.3 GHz. The optimized Z-shape patch antenna with I-slot has a SWR of 1.23 at 3.5 and 4.3 GHz.

**Directivity:** The most important parameter of the patch antenna. Fig. 5 (a), 6(a) show the radiation pattern of both un-optimized and optimized antenna. For optimized Z-shape patch antenna with I-slot the maximum directivity achieved is 5.93 dB which is 26% more as compared to the un-optimized Z-shape patch antenna with I-slot. 2-D Radiation pattern polar plot for $\Phi=0^\circ$ at the frequencies for both optimized and un-optimized Z-shape patch antenna with I-slot is shown in Fig. 5, 6.

**Gain:** Fig. 5(b), 6(b) show the radiation pattern of both un-optimized and optimized antenna. For optimized Z-shape patch antenna with I-slot, the maximum gain achieved is 1.53 which is 19% more as compared to the un-optimized Z-shape patch antenna with I-slot.
5. Conclusion

While optimizing the antenna parameter, the overlapping problems most often encountered using HFSS. The best possible optimization is done with the calibration and redesigning of the antenna in HFSS simulation tool. The Z-shape patch antenna with I-slot is optimized using discrete particle swarm optimization algorithm. Now the results of both the un-optimized antenna as well as the optimized antenna are compared. These results are presented in the table 2 below. The proposed antenna both Z-shape patch antenna with I-slot will work in the frequency range of 3.5 GHz and 4.3 GHz which covers the frequency of operation of Wi-Max / S-band and C-band satellite application. That’s why it is multipurpose antenna. From the table it is observed that the performance of the optimized Z-shape patch antenna with I-slot using discrete particle swarm optimization algorithm is better than the un-optimized in terms of the return loss, VSWR.

Table 2. Comparision of unoptimized and optimized result

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Frequency (GHz)</th>
<th>Return loss (dB)</th>
<th>Bandwidth (MHz)</th>
<th>VSWR</th>
<th>Directivity</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-optimized Z-shape with I slot patch antenna</td>
<td>3.5, 4.3</td>
<td>-18.88, -16.42</td>
<td>140.6,131.5</td>
<td>1.25,1.35</td>
<td>5.67</td>
<td>1.34</td>
</tr>
<tr>
<td>Optimized Z-shape with I slot patch antenna</td>
<td>3.5, 4.3</td>
<td>-19.40, -19.51</td>
<td>141.8,125.4</td>
<td>1.23</td>
<td>5.93</td>
<td>1.53</td>
</tr>
</tbody>
</table>
References