Reverse Design of a Dual-Band Microstrip Patch Antenna Based on Binary Particle Swarm Optimization

Hui Chen[1], Long Zhang[1]*, Yaling Chen[1], Chunxu Mao[2], Wenting Li[1], Yejun He[1]
[1]College of Electronics and Information Engineering, Shenzhen University, 518060, China
[2]Institute for Communication Systems (ICS), University of Surrey, UK
Email: long.zhang@szu.edu.cn

***Abstract*—A compact dual-band microstrip patch antenna operating at 2.18 and 2.45 GHz is proposed in this paper. The patch area of the antenna is discretized into small squares of the same size, and the binary particle swarm optimization (BPSO) algorithm is used to search for the optimal arrangement of these squares. Compared with traditional patch antenna design method, the proposed intelligent algorithm-assisted design method saves optimization time and provides distinct antenna performance.**

Keywords—Binary particle swarm optimization, dual-band antenna, microstrip patch antenna.

I. INTRODUCTION

Microstrip patch antenna is widely deployed because of its low profile, compact size, low cost, and easy integration ability. Various patch antennas have been proposed for versatile applications. In [1], a wideband reflectarray based on patch element was introduced. A circularly polarized microstrip antenna with an octagonal star patch was proposed in [2]. And in [3], a novel ultra-wideband (UWB) reflectarray antenna for the Internet of Vehicles was presented.

The design of all aforementioned patch antennas relies on the prior knowledge of the designer and the optimal values of antenna geometrical parameters are normally acquired by parameter studies, which lead to a time-consuming and non-optimal design procedure. In recent years, intelligent optimization methods such as genetic algorithm (GA), particle swarm optimization algorithm (PSO), and neural network (NN) have been gradually applied to antenna design [4]-[6]. With the aid of these optimization methods, a more effective design paradigm is realized. Moreover, the introduction of these optimization methods often brings better antenna performance than tradiational design method.

In this paper, a dual-band microstrip patch antenna based on binary particle swarm optimization (BPSO) is proposed. The patch region is discretized as a two-dimensional [0, 1] matrix, and then the BPSO is introduced to find the optimal matrix satisfying the expected electromagnetic response. In this manner, the optimal geometry of the patch can be obtained and the reverse design of corresponding electromagnetic structure is realized.

II. BRIEF INTRODUCTION OF BINARY PARTICLE SWARM OPTIMIZATION

The BPSO is an intelligent optimization algorithm based on bird foraging behavior. Compared with other optimization algorithms, this algorithm seeks the optimal solution through iteration, which does not require many databases, and has a faster convergence speed [7]. BPSO is a solution method for discrete problems, and the solution space is only composed of 0 and 1. Suppose *N* particles are randomly distributed at different positions in the *D*-dimensional search space, and each particle has two attributes: position and velocity. During the flight, each particle changes its next flight speed and arrival position according to the optimal global position and the optimal position searched by individuals. The population position at the end of the flight represents the optimal solution [8].

The basic steps of BPSO are as follows:

- ***Step 1:*** Initializes population parameters, such as population size, search space dimension, initial velocity, and position of each particle.
- ***Step 2:*** Calculate the fitness of each particle under the current position, and update the optimal position p_{best} and the optimal global position g_{best} of each particle according to the fitness.
- ***Step 3:*** Use (1) to update the velocity of each particle. V_{t+1} and V_t represent the velocity of the particle on the *t+1* and *t* flight, respectively, and X_{t+1} and X_t represent the position of the particle at the end of the *t+1* and *t* flight, respectively. ω, c_1 and c_2 are weight parameters; $rand_1$ and $rand_2$ represent random numbers between 0 and 1. Then the sigmoid function in (2) maps the velocity to [0, 1].

$$V_{t+1} = \omega \cdot V_t + c_1 \cdot rand_1 \cdot (p_{best} - X_t) + c_2 \cdot rand_2 \cdot (g_{best} - X_t) \tag{1}$$

$$Sigmoid(V_{t+1}) = \frac{1}{1 + \exp(-V_{t+1})} \tag{2}$$

- ***Step 4:*** Use (3) to update the position of each particle. If the random number $rand_3$ $(0 < rand_3 < 1)$ is less than the result of (2), then *X* is equal to 1. Otherwise, it is 0.

$$X_{t+1} = \begin{cases} 1, & rand_3 < sigmoid(V_{t+1}) \\ 0, & otherwise \end{cases} \tag{3}$$

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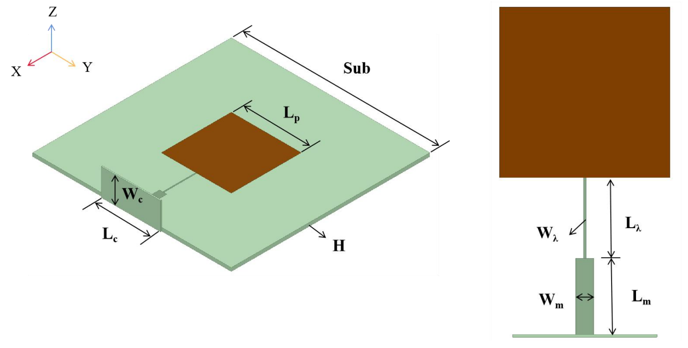


(a) (b)

Fig. 1. Geometry of a conventional microstrip patch antenna. (a) Perspective view, (b)Top view.

TABLE I. DETAILED PARAMETERS OF THE ANTENNA PROTOTYPE

Parameter	*Sub*	L_p	L_c	W_c	L_λ	W_λ	L_m	W_m
Value (mm)	90	31.7	26.9	12.2	15	0.5	14.15	3.36

- ***Step 5:*** Judge whether the end condition is met. If yes, output the current population position X as the optimal solution. Otherwise, go back to step 2 and continue the iteration.

III. INVERSE DESIGN OF DUAL-BAND MICROSTRIP PATCH ANTENNA

Fig. 1 shows the geometry of a convetional microstrip patch antenna to be optimized. The square patch is printed on the upper surface of a square Rogers RO4003 dielectric substrate with a dielectric constant of 3.55 and is connected to a 50-ohm microstrip line by a 1/4 λ impedance converter. Detailed geometric parameters of this patch antenna are shown in Table I.

A. Reverse Design Procedure

The goal of reverse design is to determine the patch shape of the microstrip antenna which has two resonances in the 2-3 GHz frequency band. Fig. 2 demonstrates the design flow, and the application of BPSO is explained as follows:

Firstly, to ensure the feeding line is connected to the patch, a rectangular patch with length Lp and width $Lp/30$ is kept on the side near the microstrip line, and the rest of the patch is discretized. The position (15mm, 15mm) is defined as the starting points of the discretized region, as shown in Fig. 3. The discrete region is represented by a two-dimensional 0 and 1 matrix W, and each element in the matrix is mapped to a 6mm × 6mm sub-region on the patch. Where 1 represents the metal, and 0 is the air.

Secondly, the population parameters are initialized. Let ω= 0.8, $c_1 = 2$, $c_2 = 2$, the population size N, the number of iterations and the dimension of search space D are 30, 20, and 25, respectively. And each element in the matrix W is randomly assigned by 0 or 1.

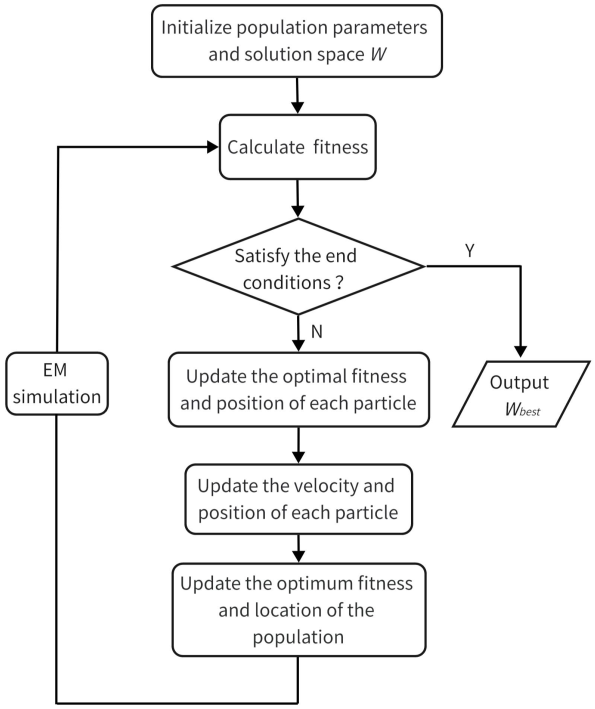


Fig. 2. Design flow for the reverse design of a dual-band patch antenna.

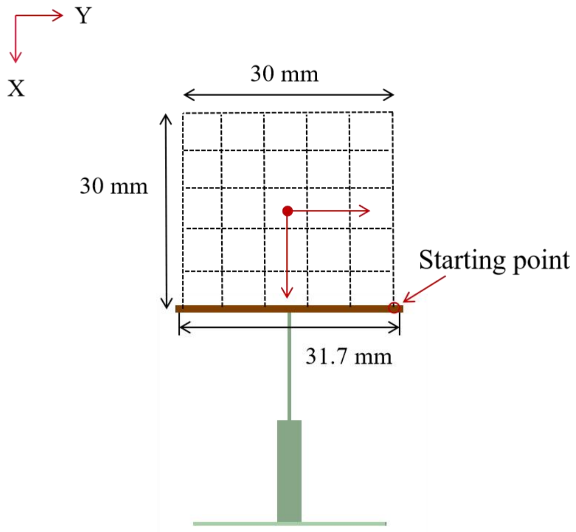
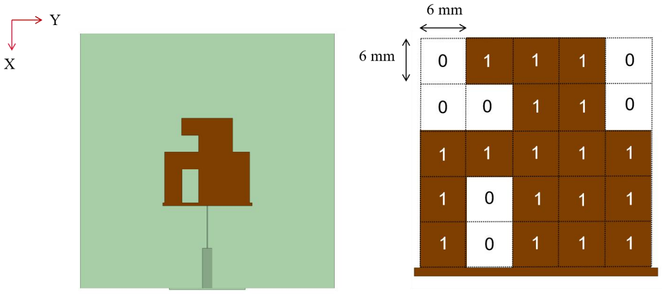


Fig. 3. Discretized region of the microstrip patch antenna.

Thirdly, the fitness function of the population is calculated by (4), where f_1, f_2, f_3, and f_4 are 2.1, 2.2, 2.4, and 2.5 GHz, respectively. The initial fitness is 0 and the end condition is that the fitness is greater than 20 dB.

$$Fitness = -S_{11}(f_1 \sim f_2) - S_{11}(f_3 \sim f_4) \tag{4}$$

Finally, the speed and position of each particle in the population are updated according to fitness, and then the design flow goes back to the third step and iterates 20 times.



0	1	1	1	0
0	0	1	1	0
1	1	1	1	1
1	0	1	1	1
1	0	1	1	1

(a) (b)

Fig. 4. The proposed dual-band patch antenna optimized by BPSO. (a) top view, (b) patch shape with optimized matrix.

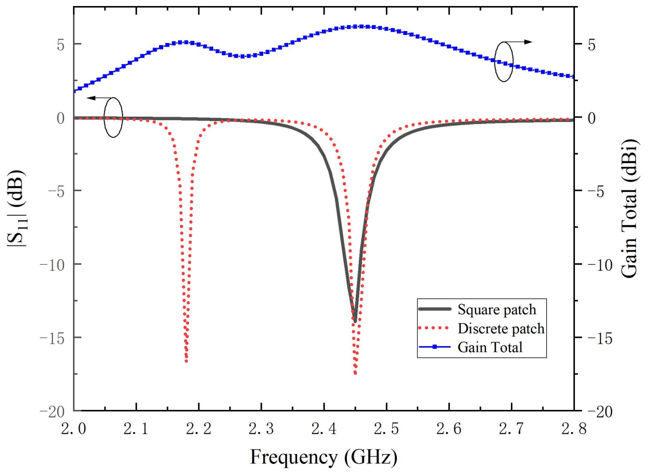
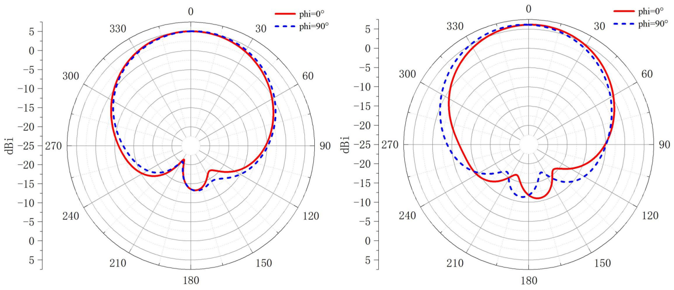


Fig. 5. Comparison of the coefficient reflection between the conventional patch antenna and the proposed antenna optimized by BPSO (red and black line). Gain of the optimized antenna (blue line).



(a) (b)

Fig. 6. Full wave simulation patterns at 2.18 and 2.45 GHz. (a) 2.18GHz; (b) 2.45GHz.

B. Results and Discussions

After 20 cycles, the final population position X is the optimal value of the matrix W, and the optimal result is shown in Fig 4. Fig. 5 shows the comparison of the reflection coefficient between the traditional patch antenna and the BPSO optimized antenna. As we can see that the traditional square patch resonates only at 2.45 GHz, and the minimum value of $|S_{11}|$ is -14 dB. After the BPSO optimization, a dual-band patch antenna resonating at 2.18 GHz and 2.45 GHz is achieved. Moreover, the gain at both resonances exceeds 5 dBi. Fig. 6 shows the radiation patterns of the proposed antenna. As shown in Fig. 6, good directional patterns occur at the two resonances. It is worth pointing out that the size of the proposed patch antenna is even smaller, indicating that the proposed method can realize better antenna performance compared to traditional antenna design method.

IV. CONCLUSION

In this paper, the discrete optimization of a conventional microstrip patch antenna is carried out using the BPSO algorithm. The $|S_{11}|$ of the optimized antenna is less than -10dB at 2.18 and 2.45 GHz, achieving good dual-band function. Compared with traditional design methods, applying intelligent algorithms in electromagnetic design improves the design efficiency and reduces the calculation cost. The experiment founds that further subdivision of the optimized region will get better electromagnetic performance, but the expansion of solution space will lead to slower convergence.

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