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A Linear-to-Circular Polarizer Optimized by Simulated Annealing Algorithm

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***Abstract*-A compact millimeter-wave polarizer that transforms a linear polarization wave into circular polarization is proposed in this paper. The presented polarizer is made of a single-layer metal plate with three ring slots, and the simulated annealing algorithm (SA) is used to optimize the size of the ring slots, which is much more efficient than the manual optimization using commercial EM tools. The optimized resonant frequency of the proposed polarizer is 30GHz, with a 3dB axial ratio (AR) bandwidth of 10%, and a minimum AR value of 0.3 dB at 30GHz.**

I. Introduction

Circular polarization antenna is widely applied in various scenarios due to its anti-interference capability and immunity of polarization mismatch [1]-[4]. Employing a linear polarization (LP) to circular polarization (CP) polarizer is a common way to realize circular polarization antennas. There are various kinds of polarizers that can achieve good LP to CP performance. For example, an electrically reconstructed circular polarizer was proposed in [5], where a metal strip is combined with a linearly polarized antenna to realize circular polarization. In [6], a new type of polarizer based on textile material is introduced, with the conversion efficiency exceeding 90% in the 1.55 GHz to 2.51 GHz frequency band. Besides, a frequency-selected surface based sub-millimeter wave polarizer was proposed in [7], which could convert linearly polarized waves into circularly polarized waves with a nested annular slot element. Although these polarizers can achieve good LP to CP performance, the design process is dependent on commercial EM tools and manual optimizations, which consumes a lot of computing time in the parametric study process. Therefore, it is very necessary to design the antenna with the help of optimization algorithm.

This paper proposes a LP-to-CP polarizer with three ring slots etched on a copper plate. As the number of geometrical parameters to be determined is up to 12, it is difficult to find the optimal combination of these parameters by human efforts. Therefor we use the simulated annealing algorithm (SA) to optimize the polarizer, leading to an efficient way in realizing a good LP-to-CP polarizer. The simulation results indicate that the axial ratio (AR) of the polarizer is less than 3dB in the frequency range from 28.4 GHz to 31.4GHz with a minimum AR value of 0.3 dB, verifying the effectiveness of the proposed method in realizing LP to CP polarizers.

II. Design and Optimization Method of The Polarizer

A. Configuration of the Polarizer

As shown in Fig.1, the proposed polarizer is made by a metal plate with a thickness of 0.1mm. The length of the two sides of the copper plate are fixed, which are DX=5.4mm and DY=4.8mm. Three ring shaped slots are etched on the plate, with the size of the rings and the position of the notches are adjustable, and detailed values of geometric parameters optimized by the algorithm are shown in Table I. In order to make the polarizer resonating at 30GHz and realize good LP-to-CP function, there are a total of 12 geometrical parameters to be determined. The radius values of the six circles are denoted as R_1,R_2, R_3, R_4, R_5, and R_6, and the angles between the three notches and the X axis are denoted by a_1, a_2, a_3, a_4, a_5, a_6. All these parameters have a great influence on the performance of the polarizer, thus should be optimized independently.

Since it is difficult to adjust these parameters manually, the simulated annealing algorithm is adopted to optimize the polarizer for achieving good polarization conversion performance. By calling the simulation software, the algorithm can find the required parameter matching within a few hours of iteration.

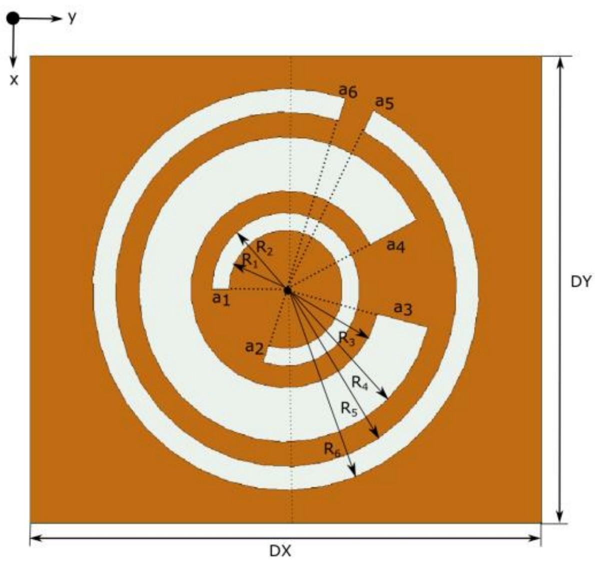

Fig. 1. The shape of proposed polarizer

TABLE I
OPTIMAL SOLUTION SPACE

R_1 (mm)	R_2 (mm)	R_3 (mm)	R_4 (mm)	R_5 (mm)	R_6 (mm)
0.6	0.78	1	1.55	1.8	2.04
a_1	a_2	a_3	a_4	a_5	a_6
270°	342°	75.6°	117°	153°	162°

B. *Optimization Procedure of the Polarizer*

The simulated annealing algorithm (SA) was first proposed in [8], and then improved in [9], [10]. It belongs to a probabilistic heuristic algorithm. Compared with the classical hill-climbing algorithm, in order to find the global optimal solution, SA uses Metropolis sampling criterion to accept a worse solution with a certain probability and jumps out of the local optimum. The Metropolis sampling criterion is usually expressed by equation (1) and (2) :

$$\Delta = F(x^*) - F(x) \tag{1}$$

$$p = \begin{cases} 1 & F(x^*) \le F(x) \\ \exp(\frac{-\Delta}{T_i}) & F(x^*) > F(x) \end{cases} \tag{2}$$

where F is calculated as a function of the antenna AR bandwidth， x=(R_1, R_2, R_3, R_4, R_5, R_6, a_1, a_2, a_3, a_4, a_5, a_6) represents the current solution, x* represents the new solution generated by the next iteration. And Δ represents the AR difference between two iterations.

Regarding the optimization of the polarizer, the annealing process is as follows:

1) Initialization: The Monte Carlo method is used to randomly generate the initial solution space and determine the number of iterations L. The initial values of the geometric parameters is: {R_1=0.5mm, R_2=0.7mm, R_3=0.95mm, R_4=1.4mm, R_5=1.7mm, R_6=2.2mm, a_1=40°, a_2=100°, a_3=140°, a_4=180°, a_5=225°, a_6=270°}, L=60.

2) Generate new solution: Slightly perturb the solution space to obtain a new solution x* by changing the value of each variable in the solution space by a certain step size. When the initial temperature is higher, the step size is larger. Once the annealing reaches a certain stage, the temperature changes slowly, and the step size should be reduced to avoid missing the local optimal solution.

3) Calculate the objective function F: In this paper, F(x) represents the relative bandwidth with axial ratio less than 3dB under the current solution x. For each set of solution space, the corresponding objective function can be calculated. The 3dB bandwidth reflects the performance of circular polarization, and thus small axial ratio is one optimization target.

4) Calculate the AR difference Δ: The AR difference which can be calculated by equation (1), according to Δ, the probability of accepting the current solution can be calculated.

5) Update solution space: New solution is received according to Metropolis criterion by equation (2). When the axial ratio bandwidth of the new solution x* is less than the old solution x, the new solution x* is accepted, otherwise x* is accepted with a very small probability.

6) Iterative calculation: Go to step *2)* to continue the iteration until the number of iterations reaches L, and the final solution is the optimal solution.

III. RESULTS AND DISCUSSION

The axial ratio results of the proposed polarizer under incident LP waves with different incident angles are shown in Fig.2. The proposed polarizer has an axial ratio less than 3dB in 28.4 GHz to 31.4GHz frequency band with 0° incident waves, and the minimum axial ratio of 0.3dB occurs at the center frequency of 30GHz. Besides, when the incident wave rotates 45°, the axial ratio has little variations, indicating that the proposed polarizer is able to transform LP waves with different polarization angles to CP waves.

IV. CONCLUSION

This paper presents a LP to CP polarizer consisting of a single-layer copper plate with ring etched slots. The proposed millimeter -wave polarizer can transform a linear polarization wave into a circular polarization with good conversion performance. The simulation results indicate that the axial ratio of the transferred wave is less than 3dB within the frequency rang from 28.4 GHz to 31.4 GHz. What is more , the simulated

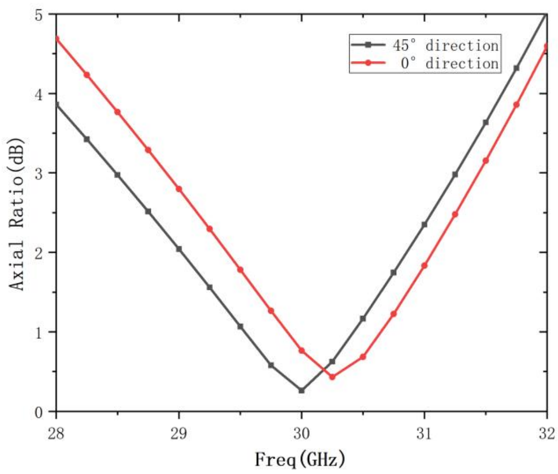

Fig.2 The axial ratio of the proposed polarizer under different incident wave directions.

annealing algorithm is used to optimize the proposed polarizer, which is much more efficient than traditional parametric study method in optimizing such a polarizer.

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