A Linear-to-Circular Polarizer Optimized by

Simulated Annealing Algorithm

Hui Chen¹, Long Zhang^{1*}, Chunxu Mao², Jian Dong³, Yejun He¹

¹College of Electronics and Information Engineering, Shenzhen University rizer Optimized by
g Algorithm
, Jian Dong³, Yejun He¹
Shenzhen University, 518060, China
, University of Surrey, UK
al South University, 410083, China
ong.zhang@szu.edu.cn **Dptimized by
orithm**
, Yejun He¹
, Yejun He¹
f Surrey, UK
f Surrey, UK
ersity, 410083, China
ru.edu.cn

ear-to-Circular Polarizer Optimized by
Simulated Annealing Algorithm
Fuicherl, Long Zhang^{1#}, Chunxu Mao², Jian Dong³, Yejun He¹
² Institute for Communication Expinemering, Shenzhen University, 518060, China
ge of a**r-to-Circular Polarizer Optimized**
 imulated Annealing Algorithm

Hui Chen¹, Long Zhang^{1*}, Chunxu Mao², Jian Dong³, Yejun He¹

of Electronics and Information Engineering, Shenzhen University, 518060, China

 $\begin{array}{c} \textbf{linear-to-Circular Polarizer Optimized by} \\ \textbf{Simulated Annealing Algorithm} \\ \textbf{Hui Chen!, Long Zhang^{1*}, Chunxu Mao², Jian Dong³, Yejun He¹ \\ \textbf{''College of Electronics and Information Engineering, Shemot University, of Survey, UK \\ \textbf{``College of Computer Science and Engineering, Central South University, 410083, China} \\ \textbf{Email: } 2017132005@email.szu.educn, longzhang@szu.educn \end{array}$ **ar-to-Circular Polarizer Optimized by
imulated Annealing Algorithm**
Hui Chen¹, Long Zhang^{1*}, Chunxu Mao², Jian Dong³, Yejun He¹
of Electronics and Information Engineering, Shenzhe University, 518060, China
^{2 I} 3College of Electronics and Information Engineering, Shenzhen University, 518060, China
3College of Electronics and Information Engineering, Shenzhen University, 518060, China
3College of Electronics and Information Engine -to-Circular Polarizer Optimized by

mulated Annealing Algorithm

Chen¹, Long Zhang^{1*}, Chunxu Mao², Jian Dong³, Yejun He¹

lectronics and Information Engineering, Shenzhen University, 518060, China

titute for Co **Abstract-A compact millimeter-wave polarizer that transforms**
 Algorithment millimeter-wave polarizer that transforms (ICS), University of College of Computer Science and Engineering, Shenzhen University of College of C **a** liment in the singular control and the simulated annealing agents. The presented than the manual optimization sing commercial polarization for the simulation of the Polarization into a linear polarization wave into cir **Simulated Annealing Algor:**

Hui Chen¹, Long Zhang^{1*}, Chunxu Mao², Jian Dong³, Yej

¹College of Electronics and Information Engineering, Shenzhen University

²College of Computer Science and Engineering, Cent II. ^DESIGN AND ^OPTIMIZATION ^METHOD OF ^THE ^POLARIZER *A. Configuration of the Polarizer*
A. Configure 2 A. Configurers of Surrey, UK
A. Configuration of Surrey, UK
A. Configuration of the Polarizer
A. Configuration of the Polarizer
A. Configuration of the Polarize

PHITENTICE COLOGET ATTACEMENTS AND SOLUTER
 plate of Electronics and Information Engineering, Shenzhen University, 518

¹College of Electronics and Information Systems (ICS), University of Surrey, U

³College of Co Hui Chen¹, Long Zhang^{1*}, Chunxu Mao², Jian Dong³, Ye¹
¹College of Electronics and Information Engineering, Shenzhen Universite
³College of Computer Science and Engineering, Central South Universite
³College Hui Chen¹, Long Zhang^{1*}, Chunxu Mao², Jian Dong
¹College of Electronics and Information Engineering, Shenzhen Un
² Institute for Communication Systems (ICS), University
³College of Computer Science and Engineer Hut Chen', Long Zhang^{1,*}, Chunxu Mao², Jian Dong²,
¹College of Electronics and Information Engineering, Shenzhen University of
²College of Computer Science and Engineering, Central South University
³College of ¹College of Electronics and Information Engineering, Shenzhen University
² Institute for Communication Systems (ICS), University of Surre
³College of Computer Science and Engineering, Central South University
Email: ² Institute for Communication Systems (IC
³College of Computer Science and Engineering, Ce
Email: 2017132005@email.szu.edu.cn
a linear polarization wave into circular polarizer that transforms
a linear polarization ² Institute for Communication Systems (

College of Computer Science and Engineering,

Email: 2017132005@email.szu.edu
 t millimeter-wave polarizer that transforms

II

are into circular polarization is proposed in

t Email: 2017132005@email.szu.edu.cn, long.zhang@szu.edu.
 Abstract-A compact millimeter-wave polarizer that transforms

inear polarization wave into circular polarization is proposed in

the with three ring slots, and the 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 s *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 r

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

(SA) is used to plate with three ring slots, and the smulated annealing agorithm

(SA) is used to optimize the size of the ring slots, which is much

more efficient than the manual optimization using commercial

metal plate with a thickn performance the set of the ring soles when the matter of the proposed in the manual optimized resonant frequency of the proposed sides of the copper plotarizer is 30GHz, with a 3dB axial ratio (AR) bandwidth of 10%. $DY=4.$ **EM tools. The optimized resonant frequency of the proposed** sides of the copper plate are fixe
polarizer is 30GHz, with a 3dB axial ratio (AR) bandwidth of 10%, $DY=4.8mm$. Three ring shaped shand a minimum AR value of 0.3 polarizer is 30 GHz, with a 3dB axial ratio (AR) bandwidth of 10%, DY=4.8mm. Three ring shand a minimum AR value of 0.3 dB at 30 GHz.

With the size of the rings a with the size of the rings and a minimum AR value of 0.3 **and a minimum AR value of 0.3 dB at 30GHz.** with the size of the rings an adjustable, and detailed v optimized by the algorithm assessenarios due to its anti-interference capability and immunity LP -to-CP function, there I. INTRODUCTION adjustable, and detailee

optimized by the algorith

secenarios due to its anti-interference capability and immunity LP-to-CP function, the

of polarization mismatch [1]-[4]. Employing a linear parameters circular polarization antenna is widely applied in various make the polarizer resonation
secenarios due to its anti-interference capability and immunity LP-to-CP function, there a
polarization mismatch [1]-[4]. Employing a Circular polarization antenna is widely applied in various make the polarizer scenarios due to its anti-interference capability and immunity LP-to-CP function, of polarization mismatch [1]-[4]. Employing a linear paramete scenarios due to its anti-interference capability and immunity LP-to-CP function, there
of polarization mismatch [1]-[4]. Employing a linear parameters to be determin
polarization (LP) to circular polarization (CP) polari of polarization mismatch [1]-[4]. Employing a linear parameters to be determined. The polarization (LP) to circular polarization (CP) polarizer is a circles are denoted as R_1, R_2, R_3 , R are common way to realize circul polarization (LP) to circular polarization (CP) polarizer is a circles are denoted as R₁,R₂, R₃
common way to realize circular polarization antennas. There between the three notches and the
performance. For example, common way to realize circular polarization antennas. There between the three notches and the
are various kinds of polarizers that can achieve good LP to CP a₃, a₄, a₅, a₆. All these parameters
performance. For exa are various kinds of polarizers that can achieve good LP to CP a₃, a₄, a₅, a₆. All these
performance. For example, an electrically reconstructed performance of the
circular polarizer was proposed in [5], where a me performance. For example, an electrically reconstructed performance of the point-
circular polarizer was proposed in [5], where a metal strip is independently.
combined with a linearly polarized antenna to realize circula circular polarizer was proposed in [5], where a metal strip is independently.

combined with a linearly polarized antenna to realize circular Since it is difficult to adjust polarization. In [6], a new type of polarizer ba combined with a linearly polarized antenna to realize circular

simplarization. In [6], a new type of polarizer based on textile simulated

material is introduced, with the conversion efficiency polarizer

exceeding 90% in larization. In [6], a new type of polarizer based on textile simulated annealing algorithm
terial is introduced, with the conversion efficiency polarizer for achieving geoeding 90% in the 1.55 GHz to 2.51 GHz frequency ba material is introduced, with the conversion efficiency polarizer for achievex ecoding 90% in the 1.55 GHz to 2.51 GHz frequency band. performance. By calling Besides, a frequency-selected surface based sub-millimeter can f exceeding 90% in the 1.55 GHz to 2.51 GHz frequency band. performance. By calling the sine exergencies are frequency-selected surface based sub-millimeter can find the required parameter wave polarized waves into circularl Besides, a frequency-selected surface based sub-millimeter can find the required parameter wave polarizer was proposed in [7], which could convert iteration.

linearly polarized waves into circularly polarized waves with a A Linear-to-Ci

Simulate

Minichar-to-Ci

Simulate

Simulate

Simulate

Point (See Similate Particular and

Point For College of Chemetra Ker

Fraince of Computer Section

Final : 20171

The presented point-term are parti

wave polarizer was proposed in [7], which could convert iteration.

linearly polarized waves into circularly polarized waves with a

neated annular slot element. Although these polarizers can

achieve good LP to CP perform linearly polarized waves into circularly polarized waves with a
mested annular slot element. Although these polarizers can
dependent on commercial EM tools and manual optimizations,
which consumes a lot of computing time i mested 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 p 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 dependent on commercial EM tools and manual optimizations,
substituty 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 th 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 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 geomet

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

plate with thr **Algorithm**

Mao², Jian Dong³, Yejun He¹

ing, Shenzhen University, 518060, China

(ICS), University of Surrey, UK

Central South University, 410083, China

.cn, long.zhang@szu.edu.cn

1. DESIGN AND OPTIMIZATION MET metally a thickness of 0.1mm.

metallical plate with a thickness of 0.1mm.

metallical plate with a thickness of Surrey, UK

metal South University, 410083, China

du.cn, long.zhang@szu.edu.cn

II. DESIGN AND OPTIMIZATION sides of the competer is shown in the competer of the corrections of the copper plate are discontinuous of Contral South University, 410083, China
du.cn, long.zhang@szu.edu.cn
du.cn, long.zhang@szu.edu.cn
A. Configuratio u Mao², Jian Dong³, Yejun He¹
eering, Shenzhen University, 518060, China
is (ICS), University of Surrey, UK
g, Central South University, 410083, China
du.cn, long.zhang@szu.edu.cn
A. Configuration of the Polarizer eering, Shenzhen University, 518060, China

as (ICS), University of Surrey, UK

g, Central South University, 410083, China

du.cn, long.zhang@szu.edu.cn

II. DESIGN AND OPTIMIZATION METHOD OF THE POLARIZER

A. Configuratio as (ICS), University of Surrey, UK
g, Central South University, 410083, China
du.cn, long.zhang@szu.edu.cn
II. DESIGN AND OPTIMIZATION METHOD OF THE POLARIZER
A. Configuration of the Polarizer
As shown in Fig.1, the propos g, Central South University, 410083, China
du.cn, long.zhang@szu.edu.cn
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 pla du.cn, long.zhang@szu.edu.cn

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 leng 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 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 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. T 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. T 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 positi independently. $Y=4.8$ mm. Three ring shaped slots are etched on the plate,
th the size of the rings and the position of the notches are
justable, and detailed values of geometric parameters
timized by the algorithm are shown in Table I. 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 an 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 geome 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 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

iteration.

TABLE Ⅰ

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) :

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

$$
p = \begin{cases} 1 & F(x^*) \le F(x) & \text{This paper presents a LP} \\ \exp(\frac{-\Delta}{T_i}) & F(x^*) > F(x) & \text{This paper presents a LP} \\ \text{single-layer copper plate with} & \text{unit.} \end{cases}
$$

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

mdomly generate the initial solution space and determine the

umber of iterations L. The initial values of the geometric

rameters is: ${R_1=0.5mm, R_2=0.7mm, R_3=0.95$ randomly generate the initial solution space and determine the $\frac{3}{3}$ number of iterations L. The initial values of the geometric parameters is: ${R_1=0.5 \text{mm}, R_2=0.7 \text{mm}, R_3=0.95 \text{mm}, R_4=1.4 \text{mm}, R_5=1.7 \text{mm}, R_6=2.2 \text{mm}, a_1=40^\circ, a_2=100^\circ, \frac{24}{5}$ R₄=1.4mm, R₅=1.7mm, R₆=2.2mm, a₁=40^o $a_3=140^\circ$, $a_4=180^\circ$, $a_5=225^\circ$, $a_6=270^\circ$ }, 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 $f(x)$ is initial temperature in higher the step size in larger. 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.

 R_6 corresponding objective function can be calculated. The 3dB (mm) and thus small axial ratio is one optimization target. *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 bandwidth reflects the performance of circular polarization,

> *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

 $\Delta = F(x^*) - F(x)$ (1) the proposed polarizer is able to transform LP waves with 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 different polarization angles to CP waves.

IV. CONCLUSION

 $-\Delta$ $F(x^*) > F(x)$ (2) This paper presents a LP to CP polarizer consisting of a T_i , T_i , T_i , T_i , T_i , T_j , T_i , T_j , T_j , T_i , T_j , 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 isless 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.

ACKNOWLEDGMENT

This work is supported in part by the National Natural Science Foundation of China under Grants 61801299, 62101341, and 62071306, in part by the Natural Science Foundation of Guangdong Province under Grant [7] 2020A1515011037.

REFERENCES

- [1] R. -S. Chen et al., "S-Band Full-Metal Circularly Polarized Cavity-Backed Slot Antenna With Wide Bandwidth and Wide Beamwidth," *IEEE Trans. Antennas Propag.* vol. 69, no. 9, pp. 5963-5968, Sept. 2021.
- [2] L. Zhang et al., "A Quad-Polarization Reconfigurable Antenna With Suppressed Cross Polarization Based on Characteristic Mode Theory," *IEEE Trans. Antennas Propag.* vol. 69, no. 2, pp. 636-647, Feb. 2021.
- [3] L. Zhang et al., "Wideband High-Efficiency Circularly Polarized SIW-Fed S-Dipole Array for Millimeter-Wave Applications," *IEEE Trans. Antennas Propag.* vol. 68, no. 3, pp. 2422-2427, March 2020.
- [4] L. Zhang, S. Gao, Q. Luo, W. Li, Y. He and Q. Li, "A Wideband Circularly Polarized Tightly Coupled Array," *IEEE Trans. Antennas Propag.* vol. 66, no. 11, pp. 6382-6387, Nov. 2018.
- [5] Y. Cheng and Y. Dong, "A High-Efficiency Electrically Reconfigurable Circular Polarizer and Its Array Application," *IEEE* Antennas and Wireless Propagation Letters, vol. 20, no. 12, pp. 2314-2318, Dec. 2021.
- [6] T. Md Hossain et al., "Broadband Single-Layered, Single-Sided Flexible Linear-to-Circular Polarizer Using Square Loop Array for S-Band Pico-Satellites," *IEEE Access*, vol. 7, pp. 149262-149272, 2019.
- [7] M. Euler, V. Fusco, R. Cahill and R. Dickie, "325 GHz Single Layer Sub-Millimeter Wave FSS Based Split Slot Ring Linear to Circular Polarization Convertor," *IEEE Trans. Antennas Propag.* vol. 58, no. 7, pp. 2457-2459, July 2010.
- [8] Steinbrunn, M., G. Moerkotte, and A. H. Kemper . "Heuristic and randomized optimization for the join ordering problem." Springer-VerlagPUB3755Berlin, 1997.
- [9] S. Zheng, W. Shu and Li Gao, "Task Scheduling using Parallel Genetic Simulated Annealing Algorithm," 2006 IEEE International Conference on Service Operations and Logistics, and Informatics, 2006, pp. 46-50.
- [10] G. Jianlan, C. Yuqiang and H. Xuanzi, "Implementation and Improvement of Simulated Annealing Algorithm in Neural Net," 2010 International Conference on Computational Intelligence and Security, 2010, pp. 519-522.