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Authors: Jiarui Di, Liang Dong, Wei He, Liang Dong

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Abstract

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Full Text

Preamble

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Article

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Sparse Optimization of Planar Radio Antenna Arrays Using a Genetic Algorithm

Jiarui Di[1], Liang Dong[2]*, Wei He[3]

[1]School of Information Engineering, Southwest University of Science and Technology, Mianyang 621000, China

[2]Yunnan Province China-Malaysia HF-VHF Advance Radio Astronomy Technology International Joint Laboratory, Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China

[3]The 20th Research Institute of China Electronics Technology Group Corporation, Xi’ an 710000, China

*Correspondence: dongliang@ynao.ac.cn

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Abstract: Radio antenna arrays offer numerous advantages for astronomical observations, including high resolution, high sensitivity, simultaneous multi-target observation, and flexible beam formation. However, critical performance indices such as sensitivity enhancement, scanning range extension, and sidelobe level suppression require urgent attention. Here, we propose a sparse optimization scheme based on a genetic algorithm for a 64-element planar radio antenna array. The optimization targets for the iterative process are the maximum sidelobe levels and beamwidth of multiple cross-section patterns passing through the main beam in three dimensions, along with the maximum sidelobe levels of patterns at several different scanning angles. Element positions are adjusted across iterations to select the optimal array configuration. Following sparse layout optimization, simulations of the 64-element planar radio antenna array demonstrate that the maximum sidelobe level decreases by 1.79 dB, and the beamwidth narrows by 3°. Within a scan range of $±$30°, all sidelobe levels decrease and all beamwidths narrow after sparse array optimization. This performance improvement can potentially enhance the sensitivity and spatial resolution of radio telescope systems.

Keywords: Planar antenna array; Sparse optimization; Genetic algorithm; Wide-angle scanning

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1. INTRODUCTION

Radio astronomy is an important branch of astronomical research that uses radio waves to study celestial bodies and phenomena while avoiding some limitations of traditional optical telescopes. It is largely unaffected by adverse meteorological conditions such as fog and clouds, enabling astronomical observation at longer distances with a wider field of view. Radio telescopes and their antenna arrays are essential tools, and as the research field develops, there is increasing demand for high spatial resolution, high sensitivity, and wide scanning ranges to facilitate research into the frontiers of radio astronomy, such as the reception of weak signals and high-spatial-resolution detection [1-3].

A radio antenna array is a system consisting of multiple antenna units, which may be of the same or different types. Antenna arrays are able to enhance signal reception, improve spatial resolution and sensitivity, and achieve highly sensitive directional detections through combined geometric configurations [4]. In radio astronomy observations, antenna arrays are commonly used to receive radio waves from the Sun, distant galaxies, pulsars, black holes, and other celestial bodies. The use of these arrays has greatly expanded our ability to observe astronomical phenomena.

As technology advances, the design of radio antenna arrays is constantly being optimized and enhanced, improving the performance of radio telescopes and advancing the theoretical and technological development of radio astronomy. Using antenna arrays, more complex observations can be carried out, such as employing a multi-beam approach for simultaneous observation of multiple targets. For targets such as pulsars, this enables synchronized observation and timing of multiple sources (i.e., real-time source-cold-space calibrations) [5,6], in addition to providing real-time flux calibrations of solar radio bursts. If continuous observation with a wide scanning angle can be carried out under such conditions with broad bandwidth, it can be of great significance for continuous solar radio observations and provision of information for space weather early warning and forecasting systems [7].

Antenna arrays offer significant advantages and convenience for radio astronomy research. The three parameters of the array—sidelobe level (SLL), beamwidth, and wide-angle scanning capability—are interrelated and jointly determine the performance and observing capability of the radio telescope, defining parameters such as spatial resolution, sensitivity, and scanning range of the sky area. To satisfy increasingly complex observational requirements and enhance the observing capability of radio astronomy, antenna array performance must meet higher standards: arrays should have lower SLL, narrower beamwidth, and wider wide-angle scanning capability [8,9].

Considering the relationship between the antenna array full-width-at-half-maximum (FWHM), field of view (FOV), and the number of spatially visible points, as well as the relationship between beamwidth and SLL with gain and effective area:

The field of view is defined as:

$$FOV = \pi(FWHM/2)^2 \tag{1}$$

Spatially visible points are defined as:

$$p = \frac{64800}{FOV} \tag{2}$$

where p refers to the spatially visible points. Since a smaller FOV yields more points, it provides higher resolution for the antenna array.

Gain, G, is defined as:

$$G = \frac{4\pi P_{max}}{P_0} \tag{3}$$

where P_{max} is the maximum value of the radiation intensity of the antenna, and P_0 is the input power of the antenna. When the beamwidth becomes narrower and the SLL becomes lower, it causes energy to be more concentrated in the main lobe, increasing the gain.

Effective area is given by:

$$A_e = \frac{\lambda^2}{4\pi} G \tag{4}$$

where A_e increases with G, λ is the wavelength, and A_e is the effective area.

Sensitivity is defined as:

$$S_{min} = \frac{2kT_{sys}}{A_e\sqrt{TBn_p}} \tag{5}$$

expressed in terms of the minimum detectable radio source flux S_{min}. Here, T_{sys} is the noise temperature of the entire radio telescope system, k is the Boltzmann constant, T is the observation time, B is the signal reception bandwidth, and n_p is the number of polarization channels. A larger A_e makes S_{min} smaller, increasing sensitivity.

In addition, SLL directly affects the antenna’ s anti-interference capability; if the SLL is high, noise signals from other directions may be received, affecting the accuracy of observation results.

Wide-angle scanning capability—the ability of the telescope to make observations in a wider FOV—is crucial for radio astronomy projects observing large sky areas, and they often need to have large bandwidth to provide a wide scanning sky area range. The main problem faced by ultra-wideband arrays is that they produce grating lobes when scanning a large sky area. The minimum spacing of array elements typically cannot satisfy the condition of having no grating lobes in the pattern at the upper frequency, according to the relationship:

$$d \leq \frac{\lambda}{1+\sin\theta_{max}} \tag{6}$$

where d is the array element spacing, θ_{max} is the maximum scanning angle, and λ is the wavelength. At a given wavelength λ, as θ_{max} increases, it will fail to satisfy the constraints of the antenna array pattern grating lobes. To solve this problem, the radio antenna array needs to be designed as a sparse array with unequal spacing of array elements. The sparse array can break the periodic distribution of array radiation energy in space to eliminate grating lobes. In addition, the sparse array also has other advantages, such as increasing the size of the array aperture to improve spatial resolution without requiring amplitude weighting to achieve low SLL. Based on these advantages, sparse optimization has become an active research topic in the field of antenna arrays [10].

This study modifies the antenna array layout structure to optimize performance. Previous research on antenna layout has mainly focused on optimizing SLL or beamwidth, while few studies have simultaneously optimized both SLL and beamwidth for wide-angle observation [11,12]. Previous studies [13] have used genetic algorithms to verify the optimization simulation of sparse arrays under specific constraints, although the optimized SLL and gate flap suppression effects are good, beamwidth has not been optimized. Xie et al. [14] optimized array elements using the sparse spacing method, focusing on SLL, beamwidth, and the number of concentric circular array units to achieve low SLL and gate suppression. Xiong [15] used a genetic algorithm together with several improved algorithms to study the sparse spreading of antenna arrays and optimized the position of array elements in planar antenna arrays to achieve a reduction in the peak paraflap level. Sun et al. [16] proposed an ultra-wideband sparse array based on rotationally symmetric distribution, combining it with a covariance matrix adaptive optimization strategy to optimize the distribution of array elements in a single region only. In this case, with the minimum spacing of the cells being the low-frequency half-wavelength, and with low SLL at different scan angles as optimization targets, the wide-angle scanning of the array is optimized in a wide bandwidth range.

The aim of this study is to investigate the use of genetic algorithms to study and analyze the sparse optimization of array element spacing in planar arrays for wide-angle observations. We carry out a sparse optimization study based on a genetic algorithm, using a 64-element antenna array as the object of study, with the aim of optimizing SLL and beamwidth of the array pattern. We employ a linear weighting method to transform the multi-objective problem into a single-objective problem, which is transformed into a fitness function of the genetic algorithm to optimize the layout of the array antenna to achieve low SLL and narrow beam performance in the wide-angle case. The optimization simulation results show that, compared with the rectangular planar array, the optimized array antenna scanning angle within $±$30° exhibits reduced SLL and narrower beamwidth.

2. TECHNIQUES AND METHODS

2.1. Rectangular Planar Array and Simulation

2.1.1. Antenna Arrays Antenna arrays are divided into two main categories in terms of array element layout: uniformly spaced arrays and non-uniformly spaced arrays. The latter is often broadly referred to as a sparse array [17]. This refers to an antenna array in which the array elements are arranged at unequal intervals and can be further subdivided into two types. The first is constructed by removing some array elements from a complete uniformly spaced array to form a non-uniform array, with the spacing of the array elements being an integer multiple of some fundamental quantity. The second type allows the spacing of the array elements to be an arbitrary value. However, due to factors such as the physical dimensions of the array elements and the mutual coupling effect between array elements, the spacing is usually suggested to be not less than half the wavelength to ensure the performance and efficiency of the antenna array. The sparse array method used in this paper is the latter one.

2.1.2. Establishing a Coordinate System In the design and analysis of rectangular planar arrays, the first step is to establish the coordinate system for the position of the array elements. There are three main coordinate systems: the antenna coordinate system (ACS), radar coordinate system (RCS), and antenna conical angle coordinate system (ACCS) [18], all of which can calculate array spatial coordinates. In engineering practice, according to specific design requirements and application scenarios, an appropriate coordinate system can be flexibly selected. Here, we choose the ACS for the calibration of the position of the array elements and related calculations, as shown in Fig. 1 [Figure 1: see original paper].

In a three-dimensional orthogonal coordinate system, the radiation direction is the positive direction of Z, i.e., the direction of the front hemisphere. The antenna array is located in the XY plane. A two-dimensional case requires two spacings to indicate the spacing of the array elements: the spacing in the X-direction is recorded as d_x, and the spacing in the Y-direction is recorded as d_y. The number of array elements in the X-direction is recorded as M, the number in the Y-direction is recorded as N, and so the total number of array elements is given by MN, as shown in Fig. 2 [Figure 2: see original paper].

After defining the spacing of the array elements and the number of elements in the X and Y directions, we can find the position coordinates of the array elements in the XY plane via:

$$x_m = (m-1)d_x; \quad m = 1, 2, \dots, M; \tag{7}$$

$$y_n = (n-1)d_y; \quad n = 1, 2, \dots, N; \tag{8}$$

where x_m is the position of the mth array element in the X-direction, and y_n is the position of the nth array element in the Y-direction. Equations (7) and

(8) describe a rectangular grid of array element distributions whose centers are located at the coordinate origin (0, 0).

A signal incident along the (θ, ϕ) direction onto the array is coherently superimposed to form a synthesized signal after it is received by each array element, and its coherently superimposed voltage is given by:

$$AF(\theta, \phi) = \sum_{l=1}^{MN} C_l e^{j(2\pi/\lambda x_l \sin\theta \cos\phi + 2\pi/\lambda y_l \sin\theta \sin\phi)} \tag{9}$$

where the array factor $AF(\theta, \phi)$ is a function of the wavelength λ, x_l and y_l are the array element spacings, and C_l is the aperture distribution, where the array element spacing is calculated from Equations (7) and (8). θ is the angle of incidence. C_l can be expanded into the form of complex voltages, allowing Equation (9) to be changed into:

$$AF(\theta, \phi) = \sum_{l=1}^{MN} e^{j[(2\pi/\lambda x_l \sin\theta \cos\phi + 2\pi/\lambda y_l \sin\theta \sin\phi) - (2\pi/\lambda x_l \sin\theta_0 \cos\phi_0 + 2\pi/\lambda y_l \sin\theta_0 \sin\phi_0)]} \tag{10}$$

where (θ_0, ϕ_0) is the beam pointing of the array. The synthesized antenna array pattern is obtained by the product of the array element pattern EP and the array factor AF. The antenna array pattern synthesis formula is:

$$F(\theta, \phi) = EP \times AF \tag{11}$$

where $F(\theta, \phi)$ is the antenna array pattern. In this paper, for the study of a planar antenna array, only ideal conditions are considered in the derivation of the antenna array pattern function and the establishment of the optimization model: if all antenna units are identical, have the same excitation amplitude, and are omnidirectional antenna units, then the element factor (EP) of the array element is 1. Substituting Equation (10) into Equation (11), the expression for the planar antenna array pattern is derived as:

$$F(\theta, \phi) = \sum_{l=1}^{MN} e^{j[(2\pi/\lambda x_l \sin\theta \cos\phi + 2\pi/\lambda y_l \sin\theta \sin\phi) - (2\pi/\lambda x_l \sin\theta_0 \cos\phi_0 + 2\pi/\lambda y_l \sin\theta_0 \sin\phi_0)]} \tag{12}$$

2.2. Genetic Algorithm-based Antenna Array Sparse Optimization Analysis

2.2.1. Algorithms A genetic algorithm is a heuristic search algorithm that simulates the mechanism of biological evolution in nature, with design inspired by Darwin' s principles of natural selection and genetics. As a powerful optimization tool, genetic algorithms are known for efficiency, practicality, and robustness, and are especially suitable for solving NP-hard problems as well as complex nonlinear, multimodal, and multi-objective optimization problems. NP-hard problems are a very important class of problems in computer science and mathematics, which are at least as difficult to solve as NP-complete problems (i.e., nondeterministic problems that can be verified in polynomial time). Genetic algorithms have shown excellent application potential in many fields such as engineering, computer science, and economics. Thus, the application of genetic algorithms provides an effective solution for optimal design in the sparse array element placement problem [19].

The optimization process of sparse optimization for planar arrays using a genetic algorithm follows these steps. First, an initial population with real values is generated and the gene sequences of each individual are ordered; in this study, the genes of the individuals represent the array element spacing and each individual represents the array element arrangement. Next, the fitness of the population is evaluated. The fitness value is a combination of the SLL and beamwidth of the array, and it is determined by whether the preset termination condition is met. If it is met, the algorithm is terminated, meaning that the solution of the array element spacing that meets the optimization condition has been found, and the output array element spacing is the final optimization result. If it is not satisfied, iterative evolution of array element alignment individuals is performed by selection, crossover, mutation, and genetic operations, and the gene sequences are again ordered and mapped to the actual spacing. For the progeny population produced by each round of iteration, the termination condition judgment is repeated until the termination criteria are satisfied. The flowchart of the spacing algorithm is shown in Fig. 3 [Figure 3: see original paper].

2.2.2. Population Initialization First, a planar array is created as the initialization population with an array aperture of $L \times H$; the number of antenna elements is the same as the regular array. The array arrangement of $M \times N$ array elements, i.e., the positions of these array elements, is transformed into a two-dimensional complex matrix G with N_x rows and N_y columns. The position matrix of this array element is denoted as $dx + jdy$, where dx is the distance spacing in the X-direction, and dy is the distance spacing in the Y-direction. The spatial constraints to be satisfied by the array element distance spacing are:

$$\begin{cases} 0 \le dx_{mn} \le L \\ 0 \le dy_{mn} \le H \\ |dx_{mn} - dx_{lk}| \ge d_c \\ |dy_{mn} - dy_{lk}| \ge d_c \\ m, n, l, k \in \mathbb{Z}, \quad 1 \le l, m \le N_x, \quad 1 \le k, n \le N_y \end{cases} \tag{13}$$

where L is the array aperture in the X-direction, H is the array aperture in the Y-direction, and d_c represents the minimum array element spacing constraint, which is taken as half the wavelength here. At this point, let the constrained array element position matrix be f, and the constraint matrix be C, where $f(m,n) = x_{mn} + jy_{mn}$ and $C(m,n) = (m-1)d_c + j(n-1)d_c$. Then, the array element position matrix G is shown by:

$$G = f + C \tag{14}$$

From the constraints, it can be obtained that the range of the parameter variable boundaries in the X-direction is $0 < x_{q,g} < [L-(N_x-1)d_c]$, and the range of the parameter variable boundaries in the Y-direction is $0 < y_{q,g} < [H-(N_y-1)d_c]$, where $x_{q,g}$ is the distance interval parallel to the X-axis direction, and $y_{q,g}$ is the distance interval parallel to the Y-axis direction. Thus, only the intermediate individual f needs to be operated during the genetic operation, reducing the search space and speeding up the optimization. When the number of individuals in the population is NP, each intermediate individual is shown by:

$$f_{q,g} = x_{q,g} + jy_{q,g}; \quad q = 1, 2, \dots, NP \tag{15}$$

where q is the ordinal number of the individual in the corresponding population, and g is the number of genetic generations.

Since the array aperture is fixed, the boundaries of the populations are constrained as shown by:

$$\begin{cases} dx_{1,1} = 0 \\ dx_{1,N_x} = 0 \\ dx_{N_y,1} = L \\ dx_{N_x,N_y} = L \end{cases} \tag{16}$$

and

$$\begin{cases} dy_{1,1} = 0 \\ dy_{1,N_x} = 0 \\ dy_{N_y,1} = H \\ dy_{N_x,N_y} = H \end{cases} \tag{17}$$

where dx represents the position of the array element in the X-axis direction and dy represents the position of the array element in the Y-axis direction. This ensures an array element at each of the four corners of the initialized array, preventing the array element from exceeding this boundary during subsequent optimization.

2.2.3. Selection Operations We use the "roulette" method of selection here, where the probability of an individual $f_{q,g}$ remaining in the population in Equation (15) is determined by measuring its fitness as a proportion of the population. The fitness of each individual determines its probability of being selected; the higher the fitness value, the higher the probability of being selected, and vice versa. The fitness function is given by:

$$fit_q = W_1 \times SLL_{1max} + W_2 \times SLL_{2max} + W_3 \times BW_{max} \tag{18}$$

where fit_q is the fitness value of corresponding individuals in the population, W_1, W_2, and W_3 are the weighting coefficients, SLL_{1max} is the MSLL in the antenna array pattern of the cut planes, SLL_{2max} is the MSLL of the antenna array pattern at all different scan angles, and BW_{max} is the half-power beamwidth in the antenna array pattern of the cut planes.

Since it involves the problem of multi-objective optimization, the linear weighted sum method is used here to set up the weighting coefficients for SLL and beamwidth to construct the fitness function. In addition, in order for the antenna array to have wide scanning performance, the maximum sidelobe level (MSLL) of the antenna array pattern under different scanning angles is also an optimization objective.

2.2.4. Crossover Operation The selected array element arrangement of odd-numbered individuals and the array element arrangement of even-numbered individuals are paired, and for each array element arrangement, a partial array element spacing between them is exchanged with a crossover probability P_c. The specific steps are as follows. First, an array element arrangement to be paired is taken out; then, according to the length of a bit string L, the array element arrangement to be paired is matched, and the integer k in $[1, L-1]$ is randomly selected as a crossover position. Finally, according to P_c, the crossover operation is implemented: the paired individuals exchange their respective parts of the array element spacing with each other at the crossover position, forming a new array element arrangement.

2.2.5. Mutation Operations For each array element arrangement in the population after crossover, some array element intervals are reformed as other equal array element intervals with mutation probability P_m. The specific steps are as follows. In the array element arrangement after crossover, from $p = 1\ MN$ and $q = 1\ NP$, a random number r is generated in the interval $[0, 1]$, and the (p, q) array element interval $f(p, q)$ is selected as the mutation array element interval if $r < P_m$. It is then replaced with a randomly generated parameter in the value domain as in the equations:

$$x_{pq} = \text{rand}[0,1] \times [L - (N_x - 1)d_c] \tag{19}$$

$$y_{pq} = \text{rand}[0,1] \times [H - (N_y - 1)d_c] \tag{20}$$

where $\text{rand}[0, 1]$ denotes the random generation of a value uniformly distributed within $[0, 1]$.

After the selection of individuals, individual crossover, and mutation operations, a new population is obtained, and the array element intervals in the newly generated population need to be treated again to sort the array element intervals in the population from the smallest to the largest, to obtain the new array element arrangement. The fitness calculation is performed on the newly generated array element arrangement, and the optimal array element interval is retained in the new generation population for the next genetic operation. After the above steps complete a given number of cycles or satisfy predefined conditions, the genetic algorithm is terminated and the optimal individual is output as the optimization result.

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3. RESULTS AND ANALYSIS

3.1. Array Initialization Information

A standard 8×8 rectangular planar array is sparse optimized and analyzed based on a genetic algorithm. The initial frequency of this array is 300 MHz, the spacing of array elements is $\lambda/2$, the total number of array elements is 64, and the scanning angles are $\theta = 0°$ and $\phi = 0°$. The arrangement and three-dimensional antenna array pattern of the array element are shown in Fig. 4 [Figure 4: see original paper], where the three-dimensional antenna array pattern is calculated using Equation (12). Since the three-dimensional array pattern of the antenna is symmetric about the u-axis and v-axis, and there are maximum values of SLL and beamwidth in both the u-axis and v-axis directions, subsequent observations are mainly based on this 3D orientation map sectioned for comparison with the sparse optimized results. The MSLL is -12.79 dB, and the beamwidth is 13°.

Fig. 5 [Figure 5: see original paper] shows the three-dimensional antenna array pattern cross-section diagram for $\phi = 0°$ and $\phi = 90°$.

3.2. Optimization Using the Genetic Algorithm

In the optimization of the array using the sparse algorithm, the MSLL and beamwidth are made the optimization objectives. Since the number of array elements is constant and the array spacing is to be satisfied as much as possible to be greater than $\lambda/2$, the array aperture is set to $5\lambda \times 5\lambda$, the number of populations is set to 50, the crossover rate to 0.8, the mutation rate to 0.08, the maximum number of genetic generations to 100, and the scanning angles are $\theta = 0°$ and $\phi = 0°$.

Fig. 6 [Figure 6: see original paper] shows the array element layout after optimization by the genetic algorithm, and the evolution of fitness values in genetic iterations calculated with Equation (18), where the fitness evolution curve tends to reach the optimal layout after 50 iterations. The element spacing optimized by the genetic algorithm is shown in Table 1 , where the real numbers are the element spacing in the X-direction and the imaginary numbers are the element spacing in the Y-direction in meters, N_x for rows, N_y for columns.

The optimized three-dimensional antenna array pattern is shown in Fig. 7 [Figure 7: see original paper], where the three-dimensional antenna array pattern is calculated from Equation (12). Its beamwidth at scanning angle $\theta = 0°$ and $\phi = 0°$ is 10° and the MSLL is -14.58 dB.

3.3. Comparison of Performance Improvement after Sparse Optimization

To compare the initial uniform plane antenna array pattern with the sparse optimized pattern more intuitively, the two three-dimensional patterns are given a longitudinal section at 15° intervals. Since the three-dimensional pattern of the initial planar array is symmetric about the u-axis and v-axis, the section antenna array pattern with $\phi = 0°$ of the initial plane array is used here to compare with the optimized section antenna array pattern. The comparative plots are shown in Fig. 8 [Figure 8: see original paper] and the beamwidths and MSLL values are shown in Table 2 .

Through the scanning angles $\theta = 0°$ and $\phi = 0°$, the MSLL is -12.79 dB before sparse optimization and -14.58 dB after sparse optimization. The beamwidth is 13° before sparse optimization and 10° after sparse optimization. The MSLL decreases by 1.79 dB and the beamwidth narrows by 3° through sparse optimization, demonstrating that sparse optimization of the array element spacing of the rectangular planar array using the genetic algorithm can reduce the MSLL and narrow the beamwidth.

To verify the scanning characteristics of the array at a wide scanning angle, we analyze and compare the simulation data after changing the scanning angle of the antenna array. Fig. 9 [Figure 9: see original paper] illustrates the main beam cutaway for the sparse optimization with pitch angle θ varying from $-40°$ to $40°$ and azimuth ϕ fixed at $0°$. Tables 3 and 4 list the corresponding beamwidth data and the MSLL.

The results show that the MSLL decreases significantly and the beamwidth narrows as the scan width moves across the $\pm30°$ range. However, the beamwidth gradually widens with increasing angle, and the MSLL also shows a rising trend. When θ exceeds $30°$, the MSLL is higher than before optimization.

Here, the rectangular planar array is compared with the antenna array pattern section after sparse optimization with $\theta = 30°$ and $\phi = 30°$. As an example, Fig. 10 [Figure 10: see original paper] shows the comparison of the planar rectangular array with the antenna array pattern section after sparse optimization when $\theta = 30°$ and $\phi = 30°$, and Fig. 11 [Figure 11: see original paper] shows the comparison when $\theta = \pm30°$ and $\phi = 45°$.

As shown in Fig. 10 and Fig. 11, sparse optimization produces significant improvement in the performance of the antenna array under scanning angles of $\theta = \pm30°$, $\phi = 30°$ and $\theta = \pm30°$, $\phi = 45°$. The specific data are shown in Table 5 . After sparse optimization, the MSLL is reduced by 0.65 dB and the beamwidth is narrowed by 4.5° when the scanning angle is $\theta = 30°$ and $\phi = 30°$; the MSLL is reduced by 2.24 dB and the beamwidth is narrowed by 4° when the scanning angle is $\theta = \pm30°$ and $\phi = 45°$. This result shows that the sparse optimized scanning angles of $\theta = \pm30°$, $\phi = 30°$ and $\theta = \pm30°$, $\phi = 45°$ are both effective in reducing the MSLL and narrowing the beamwidth.

4. CONCLUSIONS

In this study, we primarily explore the optimal design of genetic algorithms for the sparse optimization of element spacing in rectangular planar arrays. Our core strategy is to employ a linear weighting method to transform the multi-objective optimization problem involving MSLL and beamwidth into a single-objective problem. Subsequently, we use the genetic algorithm to optimize the layout of the antenna array, aiming to achieve low MSLL and narrow beamwidth characteristics for the antenna array under wide-angle scanning conditions.

Specifically, we select the MSLL and beamwidths of multiple tangent antenna array patterns passing through the main beam by slicing the three-dimensional antenna array patterns. The MSLL of the antenna array patterns at different scan angles are the optimization objectives. To transform the multi-objective optimization problem into a single-objective problem, we use the linear weighting method, and this single objective is transformed into a fitness function in the genetic algorithm. By iteratively solving the genetic algorithm, we obtain the optimal array arrangement scheme.

The simulation results show that after sparse optimization, the MSLL decreases by 1.79 dB, and the beamwidth narrows by 3°. In addition, to verify the performance of the sparse optimization under wide-angle scanning conditions, we select specific scanning angles ($\theta = \pm 30°$, $\phi = 30°$; $\theta = \pm 30°$, $\phi = 45°$) for detailed performance verification of the tangent antenna array pattern of the overall beam. The results show that sparse optimization of the antenna array exhibits improvement in both SLL and beamwidth for θ within a scan width of $\pm 30°$.

Here, sparse optimization is only performed for a single frequency point, but as radio astronomy develops, to carry out a wide range of sky scanning, the wide bandwidth required may cause grating lobes. To effectively address this problem, the periodic pattern of the radiated energy from the array can be disrupted by using an unequal spacing array element layout, which in turn achieves the purpose of reducing or eliminating the grating lobe effect. Future work will focus on sparse optimization for ultra-wideband arrays.

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AUTHOR CONTRIBUTIONS

Jiarui Di wrote the manuscript. Liang Dong supervised and organized the manuscript. Liang Dong and Wei He gave suggestions of conceptual ideas and language improvements for the manuscript. All authors read and approved the final manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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