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Beam control method for multi-array antennas based on improved genetic algorithm

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Abstract

In the rapid development of modern science and technology, the human communication system has developed to 5G, and antenna in the related equipment research and technology application has also shown a positive role. With the increasing demand for antennas and their application scope, people have put forward more requirements on the beam shape of antennas. Therefore, it is very important to control the beam of multi-array antenna based on improved genetic algorithms in the new era. Therefore, on the basis of understanding the genetic algorithm and its application content, this paper studies the future development of related technologies based on the design content and test results of the broadband low-side lobe and high-gain microstrip display antenna developed in the new era.

Keywords: genetic algorithm, array, the antenna, beam, low side lobe, high gain, microstrip, display antenna, design.**AMS 2010 codes:** 76M55

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1 Genetic algorithm and its application

1.1 Standard genetic algorithm

Definition 1. Assuming that the fitness of an individual i is expressed as f_i , and the number of individuals in the population is NP , then the probability formula of its being selected is

$$p_i = f_i / \sum_{i=1}^{NP} f_i \quad (i = 1, 2, \dots, NP).$$

Theorem 1. At this point, the probability of individual selection is directly related to fitness, and with the improvement of fitness, the probability of individual selection will also increase, otherwise, the probability will decline.

Proof. In essence, the standard genetic algorithm was put forward by American scholars in the mid-1970s, which can not only be used for mutation operation but also for crossover operation [1].

Proposition 2. In the genetic algorithm, the n -dimensional decision vector $X = [x_1 x_2 \dots x_n]^T$ is marked by n and expressed by the symbol string formed by X_i ($i = 1, 2, \dots, n$), and then $X = X_1 X_2 \dots X_n \Rightarrow X = [x_1 x_2 \dots x_n]^T$ can be obtained. The specific application process is shown in Figure 1.

Fig. 1 Application flow of the genetic algorithm.

1.2 Application of antenna beam shaping

In the construction and development of the new era, no matter what type of radio facilities, it is necessary to radiate or receive electromagnetic waves on the basis of the reasonable use of antennas. Thus, the antenna is not only an essential basic content of the development of related equipment but also the focus of research and development in the field of technology in the new era. In essence, antennas have two main functions in communication facilities: one is to refer to the energy conversion and the other is to specify the radiation or reception. Nowadays, with the expansion of antenna application scope, social development and technical innovation have raised the requirements for it, and some scene applications also have a new view on antenna

patterns. In this context, in order to better respond to the antenna application requirements in various fields, the improved genetic algorithm can be combined with a deep exploration of the relevant technology methods and, thus, put forward a new control method [2–4].

Lemma 3. Using genetic algorithm to shape the antenna beam, we only need to know the antenna pattern and the target pattern, then we can use comparative analysis to determine the fitness of the algorithm, and then we can take the amplitude and phase set in the array antenna as the group individual, then we can do the relevant calculation and analysis. In general, the pattern of the array antenna can be calculated according to the formula

Corollary 4. Where represents the element pattern of the array antenna and S represents the factor of the antenna.

Conjecture 5. If an antenna array contains M antenna elements, then the pattern of the M TH element in the array is, and the corresponding function formula can be expressed as.

Example 6. Assuming the values are the same for all the cells, you can change the above formula to. Wherein represents the orientation pattern of the unit and S represents the factor of the antenna.

Note 7. Nowadays, in the background of the continuous increase in the demand for wireless communication networks, antenna design based on wireless communication equipment has also been paid attention to and concerned by people. Take the design of dual-polarisation metal oscillator antenna unit as an example, it involves five parts in the design, including the metal oscillator, the feed coaxial, the feeder, the support column and the reflection cavity, and the overall structure is very compact. Based on the circuit equivalent diagram of the gap balance feed model shown in Figure 2, it can be seen that:

Fig. 2 Equaliser circuit equivalent diagram.

Expression 1. First, $U_4 = U_2$ at the output end because of the short circuit between the inner conductor and the upper outer conductor, and the voltage formula between the two can be clearly expressed as $U_a = U_4 + U_2 = 2U_1$.

Expression 2. Second, the voltage $U_3 = 0$ at the input port because there is a segment phenomenon between the outer conductors of the upper and lower parts, and so the formula $U_i = U_1 + U_3 = U_1$ can be obtained. At the same time, since I_3 does not pass through the inner conductor, $I_i = I_1$.

Expression 3. Third, the input impedance formula of the coaxial mode is $Z_1 = \frac{U_1}{I_1} = Z_c \frac{Z_2 + jZ_c \tan kl}{Z_c + jZ_2 \tan kl}$, where $Z_2 = U_2/I_2$ and Z_c represent the characteristics of impedance and k represents the constant of phase.

Expression 4. Fourth, in the two-wire die, the formulas $2U_4 = jI_4 \tan kl$ and $I_4 = 2U_4 / jZ_d \tan kl$ can be obtained because the upper and lower lines at the input port are short circuits. Wherein, Z_d represents the characteristic impedance of the transmission line constituted by the internal conductor. By integrating the above formulas, the impedance formulas of the output port can be obtained as $Z_o = \frac{U_o}{I_o} = \frac{2U_2}{I_2/2 - I_4}$ and $Z_2 = \frac{1}{4} \frac{jZ_o Z_d \tan kl}{Z_o + jZ_d \tan kl}$.

By (1) and (4), because $U_i = U_1, I_i = I_1$, the calculation formula of the output port $Z_{in} = \frac{U_i}{I_i} = Z_c \frac{4Z_c Z_d \tan^2 kl - j4Z_c Z_o \tan kl - jZ_o Z_d \tan kl}{Z_o Z_d \tan^2 kl - 4Z_c Z_d - j4Z_c Z_d \tan kl}$ can be obtained.

In the case of $l \rightarrow \lambda/4, \tan kl \rightarrow \infty$, you get $Z_{in} = \frac{4Z_c^2}{Z_o}$. In this case, let us say $Z_{in} = Z_c$, so $Z_o = 4Z_c$ or $Z_c = Z_o/4$.

2 Design and analysis of wideband low-side lobe high-gain microstrip display antenna

2.1 Introduction

In this paper, we study a kind of antennas that have the characteristics of wide bandwidth, low-side lobe and high-gain microstrip antenna design on display form; its main characteristics are suspended stripline air as a power network, using the parasitic patch to improve the bandwidth of the antenna and then using Taylor weighted side lobe drop in order to meet the expected requirements of broadband and low-side lobe requirement. This kind of antenna has the advantages of low loss and high power in practical applications because the suspended air stripline is used as the power component network.

2.2 The target

In this paper, the antenna design needs to ensure that the frequency is controlled between 14 GHz and 15.2 GHz, and the specific data are shown in Table 1.

Table 1 Design indicators

Working bandwidth	Horizontal beam width	Pitch beam witch	Gain	Side lobe level
8%	<6.5°	<40°	>20.5 dB	<-18 dB

Because the design of the display antenna requires a low paraboloidal surface, the best choice is the microstrip antenna, and because the power of this kind of antenna is too large, it needs to use the air suspended stripline structure for transmission. In this process, it helps the electromagnetic field to be concentrated in the air without considering the influence of the medium on its composition. At this time, the dielectric constant of the whole transmission line is very close to the dielectric constant of the air, which can be regarded as 1. At the same time, it is difficult to design the power division network and the antenna on the same floor, so it is necessary to choose a double-layer structure to make the power division network on the backboard. The advantage of this design is that it can control the influence of parasitic radiation on the microstrip line and promote the side lobe to descend faster. In addition, since the bandwidth of the lateral direct-fed rectangular microstrip patch antenna is relatively narrow, most of which is controlled at about 3%, it is difficult to meet the expected design requirements. Therefore, in order to expand the impedance bandwidth it has, a parasitic patch can be added to the radiation patch to form a resonance point adjacent to each other and to ensure that the final microstrip array antenna and its bandwidth meet the design requirements.

2.3 Unit design

The Q value response generated by the antenna under the influence of radiation is approximately inversely proportional to the electrical thickness of the antenna itself, H/λ , and the impedance bandwidth of the patch antenna can be expanded by increasing the thickness of the antenna medium, which is one of the most common operation methods at present. However, with the increase of the value of H/λ , it is easy for the surface waves to appear on the surface of the patch. Therefore, in the research and design of this paper, on the basis of adjusting the equivalent circuit of the antenna, the method of the multi-tuning loop is used to improve the impedance bandwidth of the patch. In order to achieve this design requirement, according to the analysis of the current application form of technology, it is necessary to use a two-layer antenna structure, in which the upper part belongs to the metal patch, also known as the parasitic patch, and the lower part is called the radiation patch. The effective dielectric constant formed by the whole structure is different, so it is easy for the antenna to generate two resonant points near the frequency, so as to improve the overall bandwidth [5–7].

In this two-layer design, called symmetrical, the main lobe beam width of the patch antenna becomes too

narrow due to the guiding effect of the upper conductor patch, thus increasing the gain actually contained. After the selected medium plate and antenna unit structure is defined, the model as shown in Figure 3 should be constructed with the electromagnetic simulation software, which provides an effective basis for subsequent simulation experiment analysis. After the design optimisation, the parasitic patch on the upper part and the radiation patch on the lower part of the antenna can be obtained, and the final result is far beyond the design target requirements.

Fig. 3 Unit model diagram of the array antenna.

2.4 Antenna arrangement

In front of the array antenna design, must first clear unit which contains configuration, also as shown in the table above were analysed, and the content of the need to safeguard design display when horizontal polarisation antenna, and want to combine the pitch plane and the surface of the magnetic field of the antenna, some scene information such as the relationship between the size of the analysis and design, the number of units required. In this case, the estimation formulas of antenna beam width are, respectively, where Bwe represents the width of the electric field beam, BWh represents the width of the magnetic field beam, λ represents the wavelength and D represents the size of the antenna surface.

The main factor that affects the performance of the array antenna is the power component network contained in it. Therefore, in order to ensure that the power of the display antenna meets the requirements, the design is carried out in the way of air suspension stripline as outlined above, which requires the calculation of the dielectric constant and impedance values. The specific formulas are given below.

In the case of $t/h \ll 1$, the numerical formula for the dielectric constant and impedance of the air suspended stripline is as follows:

$$Z_o = \frac{60}{\sqrt{\epsilon_e}} \ln \left[\frac{f(u)}{u} + \sqrt{1 + \left(\frac{2}{u} \right)^2} \right]$$

At the same time, we can also get:

$$f(u) = 6 + (2\pi - 6) \exp \left[- \left(\frac{30.666}{u} \right)^{0.7528} \right]$$

$$u = W / (a + b)$$

The effective dielectric constant ϵ_e of the air suspended stripline can be calculated according to the following formula:

$$\sqrt{\epsilon_e} = \left[1 + \frac{a}{b} \left(a_1 - b_1 \ln \frac{W}{b} \right) \left(\frac{1}{\sqrt{\epsilon_r}} - 1 \right) \right]^{-1}$$

At the same time, we can also get:

$$a_1 = \left(0.8621 - 0.12511n\frac{a}{b}\right)^4, b_1 = \left(0.4986 - 0.1397\ln\frac{a}{b}\right)^4$$

In the formula, T represents the thickness of the metal microstrip line, W represents its width, a represents the thickness of the dielectric plate and b represents the height of the lower suspension. Because the bandwidth requirement of antenna impedance proposed before the practical design should reach 8%, the power component network should be constructed in combination with the form of parallel feed, and then the power component ratio of different regions should be calculated. Using the Taylor weighted and array antenna pattern synthesis program provided by the MATLAB to design and analyse, the final results can be obtained as shown in Table 2.

Table 2 Calculation results of centimetre ratio

Unit	1	2	3	4	5	6
Specific value	0.38	0.48	0.52	0.65	0.78	0.96

Because the amplitude ratio of the port can be determined by optimisation calculation, the power value of one minute or two unequal power points at the upper level should be mastered in the calculation. The specific calculation formulas are $p_{2-1} = k_1^2 + k_2^2$ and $p_{2-1} = k_1^2 + k_2^2$ respectively. This is then converted to the magnitude of the voltage, as $k = \sqrt{p}$.

Among them, k_1 , k_2 , k_3 and k_4 in the formula, respectively, represent the normalised values of voltage amplitude at ports 1, 2, 3 and 4 and port 5; p_{2-1} and p_{2-2} represent the normalised values of power in the two output port regions of the power divider at the upper stage.

At the same time, because the voltage amplitude ratio of the left and right sides is the impedance ratio, in order to meet the design impedance requirements, it is necessary to use $Z_1 = Z_0 \times \sqrt{(1+g^2)}$ and $Z_2 = Z_0 \times \sqrt{\frac{(1+g^2)}{g^2}}$ to calculate, and $g = \frac{k_1}{k_2}$. Where, Z_1 in the formula represents the impedance value of the left quarter of the dielectric wavelength resistance line, Z_2 represents the impedance value of the right and Z_0 represents the impedance value of the mainline; g is the work ratio, and k_1 and k_2 are the amplitude of the work on the left and right sides.

2.5 Simulation analysis

After the completion of the above design work, the integrated research and simulation analysis should be carried out according to the power component network and unit combination obtained to ensure whether the values contained in it meet the requirements of side lobe and gain, etc. As shown in Figure 5, it is the structure diagram of the array antenna obtained in the research and design of this paper. The first layer is the parasitic patch; the second layer is the radiation patch and its medium layer; the following layer is the medium plate of the ground and power sub-network of the air cavity; and the last layer is the metal ground with air cavity.

Fig. 4 Display antenna structure diagram.

2.6 Test results

After building the simulation model of the array antenna, it is necessary to ensure that the simulation values meet the requirements of the actual design objectives and then carry out processing tests on it. The final results are shown in Figure 6.

Fig. 5 VSWR of the measured array antenna.

It can be seen from the above analysis that the straight line belongs to a VSWR of 2. It can be clear from the curve that the VSWR of this array of antennas is lower than 2 at 14 GHz–15.2 GHz, and it reaches the highest value at 14.903 GHz, namely 1.96, which is still lower than 2. It can be seen that the impedance bandwidth of the array antenna designed in this paper meets the practical design requirements, and the VSWR is less than 2 between 14 GHz and 15.2 GHz. When the designed array antenna is applied to the darkroom and the antenna far-field test method is used for operation, it must be guaranteed that it conforms to the $L > \frac{2 \times D^2}{\lambda}$ formula, which proves that the distance between the measured antenna and the transmitting antenna conforms to the far-field test conditions. In the formula, L represents the distance between the two, D represents the aperture of the antenna and λ represents the wavelength of the minimum frequency of the antenna being measured. Based on the practical operation analysis, the design antenna finally obtained meets the requirements of gain, side lobe and bandwidth [8–10].

Table 3 Analysis of physical test results

	Horizontal beam width	Pitch beam width	Gain (dB)	Side lobe level (dB)
14 GHz	5.9°	38.1°	20.8	-18.4
14.6 GHz	5.7°	36.1°	21.3	-18.6
15.2 GHz	5.4°	34.6°	22	-18

At the same time, according to the analysis shown in Table 3, at the final physical test result, compared with the design goal, the horizontal beam width of the existing array antenna at 14 GHz can reach up to 5.9°, which meets the design requirement of less than 6°. The maximum width of the pitching beam width can reach 38.1°, which meets the design requirement of less than 40°. The minimum gain value reaches 20.8 dB, which meets the design requirement of more than 20.5 dB. It can be seen that the beam control method of multi-array antenna based on the improved genetic algorithm is very effective.

3 Trend analysis

Antenna array and its content such as the beam inform, nowadays, at home and abroad, the study of this

aspect is still at the primary stage; there is a lot of work to do, especially under the background of a new era, in the face of all the various areas of innovation development that put forward new requirements and there must be new control method based on genetic algorithm research. On the one hand, the genetic algorithm and beam shaping program are combined effectively, and the electromagnetic simulation software is used to clarify the corresponding unit orientation diagram, and then the efficiency of beam shaping is improved in the simulation analysis. In this process, the improved genetic algorithm has more application value and can be optimised for different scenarios and conditions to ensure that the final applied beam shaping is more extensive. On the other hand, the design of a microstrip broadband array antenna based on the air suspended stripline introduced in this paper can not only meet the initial design requirements on the basis of controlling the side lobe amplitude but also use the improved genetic algorithm to calculate the related phase and amplitude. Under the background of the new era, it is believed that with the improvement of China's scientific research technology, the application of optimisation algorithm is bound to obtain more array antenna design ideas and effectively control the beam shape. Then, on the basis of improving the application quality and efficiency of relevant scientific research facilities in China, the current communication mode in China can be further improved.

4 Conclusion

To sum up, although the current research in this field in China is still in the development stage, with the continuous accumulation of scientific research achievements in China and more study and reference of excellent research literature and materials at home and abroad, it is inevitable that more ideas for technology development can be obtained in practice and development. At the same time, in future development, it is necessary to strengthen the training of professional talents, pay attention to master the improved genetic algorithm and array antenna design requirements and then choose the appropriate technical solutions to build a more perfect control scheme so as to improve the level of communication network research and development in China. In addition, it is necessary to strengthen the attention of the public to the relevant scientific research activities, pay attention to actively participate in the relevant research and development work; only in this way, in the context of economic globalisation, it is possible to promote China to occupy an important position on the international stage.

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