Wideband Electromagnetic Field Vector Antenna Array Technique and Direction Finding Algorithm

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Abstract. Wideband (UWB) technology has been widely used in ultra-wideband wireless communication, radar detection and other fields because of its advantages such as wide working frequency band, fast transmission rate and accurate positioning. This paper mainly studies the broadband electromagnetic field vector antenna array technology and direction finding algorithm. In this paper, the structure of a broadband resonant antenna unit is designed. The antenna unit adopts the form of printed antenna, which has both the advantages of planar antenna structure and wider bandwidth. For array antenna amplitude-phase error exists when the ideal direction, of the environment theory analyzes the mutual coupling and antenna array yuan border effect influence on beam shaper MUSIC algorithm, this paper proposes a anti-interference antenna phase characteristic difference of the calibration method of using 3 d electromagnetic simulation software HFSS, the mutual coupling matrix calculation, the ampl itude-phase error correction, and has carried on the MATLAB simulation, the simulation results show that the method of direction finding pitching Angle error of less than 1, the direction finding azimuth error is less than 2, can be used for the beidou anti-interference antenna of direction finding.

1. Introduction
In the context of modern "big data", in order to meet the communication requirements of higher capacity, faster transmission rate and longer transmission distance, traditional antennas and antenna arrays are facing a series of new changes and challenges, and the mechanical scanning mode is gradually being replaced by the electrical scanning mode with faster scanning speed and higher scanning accuracy [1]. One is that the input impedance of the antenna port is related to the scanning angle. The larger the scanning angle is, the more difficult it is to match the antenna input port. Second, the array is not an ideal isotropic radiation source, and the beam width in the array is limited, while the sweep gain of the array is related to the beam width of the element pattern. When the sweep Angle of the array exceeds the range of the 3dB beam width of the isolated element pattern, the gain of the array must decrease by at least 3dB[2]. Therefore, from the point of view of element design, to increase the scanning angle of phased array antenna, the element antenna with wide beam radiation characteristics should be designed first. A vector antenna is composed of three mutually orthogonal electric dipoles placed in co-position and three mutually orthogonal small ring antennas [3].

Vector antenna was first introduced into the field of signal processing to solve the problem of electromagnetic source localization. Later, many scholars took advantage of the properties of vector antenna to obtain all electromagnetic information and polarization information, carried out comprehensive modeling of vector antenna and applied it to signal estimation problems such as the direction of arrival and polarization parameters [4]. One is to reduce the number of basic units that
constitute the vector antenna, such as the formation of 2D, 3D vector antenna; the other is to make the six basic units non-colocation arrangement, such as using a distributed or cubic arrangement scheme [5].

In this paper, the technology of wideband array antenna is deeply studied. The directional antenna with ultra-wideband and low sidelobe is designed, and the corresponding direction finding algorithm is studied.

2. Intelligent Clinical Decision Making under Data Mining and Machine Learning Technology

2.1. Overall Antenna Design

(1) Antenna Array Design

The size of the antenna substrate is 640mm × 55mm. Such a large format will take up a lot of resources by ordinary grid section, and there are many parameters to be adjusted. Therefore, it takes a long time to directly simulate such a large antenna array. In addition, there is a 110mm metal angle reflector. The introduction of angle reflector further increases the size of the antenna, which brings great difficulties to the overall simulation. Moreover, the laboratory server hardware is limited, so it is very challenging to directly simulate and optimize the whole antenna array. HFSS in master-slave boundary condition needs only a linear arrays can be infinite periodic array simulation, at the same time can also be limited array element array simulation, in the design process, first of all units around the antenna plus a simulation design of master-slave boundary conditions, the simulation results, to limited set of array antenna simulation, using this method can greatly improve the efficiency of simulation. However, this method can only simulate the antenna design, while the feed network can not be designed together with the finite array simulated by the periodic boundary conditions. Therefore, it is necessary to design the feed network and array antenna separately, and then link them together for the overall design. By splitting the antenna in this way, the design cycle is greatly shortened.

In the array antenna, mutual coupling will occur between adjacent elements, which will have a great impact on the standing wave and directional pattern of the antenna. Therefore, many methods for restraining and compensating the mutual coupling of array antenna elements, such as the defect-ground method, the coplanar electron band gap method and the photonic crystal method, have appeared subsequently [6]. However, no matter which method of coupling suppression is adopted above, the influence of mutual coupling can not be completely eliminated. In this paper, the influence of mutual coupling has been calculated in the simulation design process using the master-slave boundary conditions.

It can be seen from the above discussion that the simulation of the finite array designed in this paper can be simulated by using the antenna array in the infinite period environment. The array composed by this method not only calculates the directional pattern multiplication of multiple array elements, but also takes into account the electromagnetic coupling between adjacent elements. Therefore, using this method to calculate the antenna of this design not only reduces the calculation scale and saves the solution time, but also has a relatively high accuracy of the simulation results.

(2) Overall Design of Antenna

The simulation results of finite array simulation using periodic boundary conditions are linked with the simulation results of feed network, and the whole design is analyzed.

The simulation results show that the minimum gain at 12GHz is 27.6dBi, the maximum half-power beam width at 12GHz is 2.6°, and the maximum gain at 18GHz is 30.3dBi. However, the suppression of sidelobe level at 18GHz and 20GHz is poor, and the sidelobe level at 18GHz is -20.7dB, which meets the requirements. However, at 20GHz, the sidelobe level is only -7 dB, which can be interpreted as the gate lobe appears because the distance between phase and element becomes smaller when the frequency is too high. Although the antenna's impedance bandwidth is up to 20GHz, the pattern bandwidth is only up to 18GHz. By comparing the standard cutting than snow, the current distribution in 15 GHZ and the simulation results and the overall structure of the feed in 15 GHZ simulation results it can be seen down 2.5 dB gain, half power beam width increased 0.5° E surface, under the sidelobe level E surface
increased 5 dB, visible when the feed network loss and the whole simulation phase inconsistency causes such as indicators are poor, but the results are within acceptable range.

The maximum half-power beam width of plane H is 24° when the frequency is 12GHz. With the increase of frequency, the half-power beam width of plane H gradually decreases, and all side lobe levels are less than -25dB. The directional pattern of plane H all meet the design requirements in the frequency band. The higher the frequency and the smaller the wavelength, the larger the relative aperture area of the included reflector plate and the smaller the half-power beam width of the H-plane. The directionality obtained by the included angle reflector and array has the same relation with frequency.

2.2. Direction Finding Algorithm

(1) Multiple signal classification algorithm

P signals incident into the direction finding antenna, which is a uniform linear array of M array elements with spacing of d array elements. Assuming that the signals are all narrowband interference and non-coherent, under the ideal condition that the amplitude and phase characteristics of the array elements are the same, the autocorrelation matrix $R_{xx}$ of the signals received by the direction finding antenna can be obtained. $R_{xx}$ is:

$$R_{xx} = APA^H + \sigma^2I$$  \hspace{1cm} (1)

Where, $A$ is the array flow pattern matrix of the narrow-band receiving signal of the m-element array antenna; $\sigma^2$ is Gaussian noise power; $J$ is the identity matrix.

According to Formula (1), $R_{xx}$ is restrained as a symmetric matrix. After eigendecomposition of $R_{xx}$, M eigenvalues $\lambda$ of $R_{xx}$ can be obtained, and the eigenvalues $\lambda$ are:

$$\lambda = \left\{ \alpha_i^2 + \sigma_i^2 = i = 1,2,\ldots,P \right\} \cup \left\{ \sigma_i^2 = P + 1,\ldots,M \right\}$$  \hspace{1cm} (2)

As can be seen from Equation (2), the signal component and the noise component together constitute the first P eigenvalues of $R_{xx}$, while the noise component constitutes the last m-p eigenvalues of $R_{xx}$. The first P eigenvalues are the sum of $\alpha_i^2$ and the noise variance, and the last m-p eigenvalues are equal to the noise variance, which is smaller than the first P eigenvalues. Therefore, the number of interference signals reaching the antenna array element can be calculated according to the eigenvalue of $R_{xx}$[7-8].

The eigensignal vector of P eigenvalues before $R_{xx}$ is $S = [s_1,s_2,\ldots,s_P]$, and the eigensignal vector of m-p eigenvalues after $R_{xx}$ is $G = [g_1, g_2,\ldots,g_{M-P}]$, and the noise subspace range($G$) and signal subspace range($S$) can be obtained, then range($G$) and range($S$) are respectively:

$$\text{range}(S) = \text{span}(s_1, s_2,\ldots,s_p), \text{range}(G) = \text{span}(g_1, g_2,\ldots,g_{M-P})$$  \hspace{1cm} (3)

The MUSIC spatial spectrum can be defined as:

$$P_{MUSIC}(\phi) = \frac{1}{\sigma_h(\phi)^H G \sigma_h(\phi)} = \frac{1}{\sigma_h(\phi)^H (I - S S^H) \sigma_h(\phi)}$$  \hspace{1cm} (4)

(2) The steps of MUSIC algorithm to calculate the source of interference signals

The MUSIC algorithm interferes with the signal to estimate the following steps [9-10] :

1) Process the interference signals received by the anti-jamming antenna and estimate its covariance matrix;

2) $R_{xx}$ matrix eigendecomposition, according to the characteristics of eigenvalue distribution, simple calculation of the number of interference signals;

3) Construct noise subspace G and signal subspace S;

4) Perform spectral peak search on MUSIC spatial spectrum according to the parameter range of the interference signal;

5) When PMUSIC($\Phi$) is the maximum value, it is the interference signal direction. Calculate the guidance vector of PMUSIC($\Phi$). According to the formula $D_S = 2\pi d \sin \theta p \lambda$, the incident direction of each interference signal can be obtained.
3. Realization and Detection of Direction Finding Algorithm

3.1. Algorithm Implementation

After the signal is processed by low noise amplifier and filter of anti-jamming antenna array, AD module carries out analog-to-digital conversion processing. NCO module and down conversion module are used to strip intermediate frequency carrier of the received signal, and the output I and Q data are searched by spectral peak of MVDR beamformers. The interference is obtained to estimate and viewed through PC terminal.

FPGA (Field Programmable Gate Array) is used to implement the anti-interference antenna direction finding algorithm. The circuit function is realized by programming and configuring the internal logic circuit of FPGA chip. FPGA can be erased and programmed repeatedly, and different types of FPGA programs can be reused, which has the advantages of high portability, short research and development cycle, low cost and so on.

According to the designed interference direction finding algorithm, the system is first conceived as a whole. The anti-interference signal direction finding algorithm is divided into several modules according to the function, and each independent module is designed. Then the VHDL language is used to import the module design into the ISE design tool, and the module function simulation is carried out after synthesizing the module. If the simulation does not meet the design requirements, re-modify the program after debugging simulation again. If the simulation meets the design requirements, the comprehensive optimization is carried out, and then the simulation is carried out after the integration of the modules. When the simulation results are different from the design expectations, the comprehensive optimization is carried out again if it is a comprehensive optimization problem. If it is not a comprehensive optimization problem, the function of the designed module should be checked. After the comprehensive simulation is consistent with the design expectation, the scheme generated by the comprehensive simulation is downloaded to the FPGA chip through J-TAG. Finally, the timing simulation and verification of the interference direction finding algorithm are carried out. If there are problems, check whether there are problems in each design module and logic wiring; If there is no problem, the function and performance of the interference signal direction finding algorithm are tested.

3.2. Algorithm Testing

After the implementation is completed, the test environment is set up for testing. Agilent E4407B spectrum analyzer is used to measure the interference signal spectrum, and B3 frequency point interference source is used to generate and control the interference signals with different power of the transmitted signals, and the signals are sent through the full frequency point antenna array. The test equipment was a certain type of military anti-jamming receiver. The performance of the direction finding algorithm of jamming signals was tested by viewing the internal data of FPGA.

4. Test Result

4.1. Single Interference Signal Source Test

Set up a signal interference signal source, the interference type is CWI, and use the online logic analysis tool to capture the test data.

|   | Pitching Angle | Error | Azimuth | Error |
|---|----------------|-------|---------|-------|
| 1 | 28.5           | 7.9   | 62.1    | 12.2  |
| 2 | 27.4           | 7.3   | 63.6    | 14.8  |
| 3 | 29.7           | 8.6   | 60.5    | 9.3   |
| 4 | 27.6           | 7.8   | 63.5    | 14.2  |
| 5 | 30.7           | 9.6   | 61.8    | 11.4  |
As shown in Table 1 and Figure 1, during the actual test, the direction finding angle deviates under non-ideal conditions, and the resolution of the spatial spectrum decreases when compared with the ideal conditions in simulation. The maximum and minimum direction-finding errors of pitching angle are 9.6, 7.1 and 8.24 respectively. The maximum azimuth error is 14.8, the minimum azimuth error is 9.3, and the average pitch angle direction finding error is 11.38. The measured pitch angle and azimuth direction finding error are both within the allowable range, and the operating results of the direction finding system are basically consistent with the simulation results, and the quantization error is small, which realizes the direction finding function of single interference signal source.

4.2. Three Interference Signal Testing

As shown in Fig. 2, the error values of pitch angle and azimuth angle in the three directions are all within the error allowable range. When the pitch angle approaches 10, the error of pitch angle is low due to the
resolution of spatial spectrum search. Compared with the results of single interference direction finding, the accuracy of direction finding is decreased. It is speculated that the reason is the error of the estimation of signal source in the matrix calculation module or the inaccurate elimination of false peak in the space spectrum search. But within the error range, the directions of the signal sources of the three interferences are all tested correctly. The system can realize the function of three interference direction finding within the allowable range of direction finding error.

According to the actual test results of different jamming signals, it can be seen that the anti-jamming antenna direction finding system can realize the function of direction finding, and the measurement error of azimuth angle is less than 15, and the measurement error of pitch angle is less than 20. However, it should be pointed out that if the pitch angle exceeds the resolution of the direction finding system, the function of direction finding cannot be realized well. When the number of interference signals is less, the accuracy of direction finding algorithm is higher.

5. Conclusions
The design and direction finding algorithm of ultra-wideband array antenna are studied in this paper. The designed antenna has the characteristics of wide frequency band, low sidelobe, good orientation, energy concentration and line polarization. It can be widely used in point-to-point communication, accurate target identification, satellite communication, signal detection and other systems. After referring to and analyzing the structure and theory of various wideband antennas, the structure of the wideband antenna unit used in this paper is designed. For array antenna amplitude-phase error exists when the ideal direction, of the environment theory analyzes the mutual coupling and antenna array yuan border effect influence on MUSIC algorithm, this paper proposes a anti-interference antenna phase characteristic difference of the calibration method, under the condition of active, using 3 d electromagnetic simulation software HFSS, calculate the mutual coupling matrix, the correction that the differences of amplitude phase characteristics, and has carried on the MATLAB simulation.

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